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ENGINEERING:

An Illustrated Weekly Journal.

EDITED BY WILLIAM H. MAW AND B. ALFRED RAWORTH.

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The Manchester Steam Users' Association.

—The ANNUAL GENERAL MEETING of the Members was held in the Board Room of the Association, at their Offices, 9, Mount Street, Manchester, on Tuesday, 30th May, ADAM DUGDALE, Esq. (Blackburn), President, in the Chair, when the following resolutions were adopted:—

Moved by the CHAIRMAN, seconded by CHARLES HEATON, Esq. (Bolton), and resolved:—

"That the Report of the Committee of Management to the Subscribers be adopted."

Moved by EDWARD PEERS, Esq. (Messrs. Robert Peers, Ltd., Bury), seconded by W. A. OGLESTHORPE, Esq. (The Mersey Docks and Harbour Board, Liverpool), and resolved:—

"That the thanks of the Association are due, and are hereby presented, to the Committee of Management for their past services, and that the following gentlemen be elected the Committee for the ensuing year, with power to add to their number:—

COMMITTEE OF MANAGEMENT.

ADAM DUGDALE, Esq., Blackburn.
CHARLES HEATON, Esq., Bolton.
H. H. SMITH-CARINGTON, Esq., Openshaw, Manchester.
HAROLD LEE, Esq., Manchester.
EDWARD HOPKINSON, Esq., D.Sc., M. Inst. C.E., M.I. Mech. E., Manchester.
HENRY WHITEHEAD, Esq., M.V.O., Bury.
The Hon. EDWARD COZENS-HARDY, St. Helens.

Moved by JOHN CLARK, Esq. (Messrs. Henry Tate and Sons, Ltd., London), seconded by JOHN MCNICHOL, Esq. (Corporation Gas Works, Mossley), and resolved:—

"That Messrs. F. W. POPPLEWELL & SON, Chartered Accountants, Manchester, be appointed Auditors of the Association's accounts for 1916, at the same remuneration as before."

Mr. DUGDALE having vacated the Chair, it was taken by CHARLES HEATON, Esq., when it was moved by HAROLD LEE, Esq. (Manchester), seconded by EDWARD HOPKINSON, Esq., D.Sc., M. Inst. C.E., M. Inst. Mech. E. (Manchester), and carried with acclamation:—

"That the thanks of the Association are due, and are cordially given, to ADAM DUGDALE, Esq., for presiding at this meeting, and for the constant service he has rendered."

EDWARD A. BATEMAN, Secretary.
9, Mount Street, Albert Square, Manchester.
31st May, 1916. E 370

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PERCY A. HAY, Secretary.
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AN ELECTRO-CHEMICAL ACTION ON GLASS.

By F. F. S. BRYSON, M.A., B.Sc., Carnegie Research Fellow in Physics, University of Glasgow.

DURING the course of some research work recently carried on in Professor Gray's laboratory, in which a Wehnelt electrolytic interrupter was used in connection with an 18-in. induction coil to produce a high-tension discharge, a disintegrating effect of the interrupted current was observed on the glass electrode holders of the interrupter at the point where the wire was sealed through the glass. This effect does not seem to have been described before.

The interrupter consists of two electrodes immersed in sulphuric acid. The cathode is a large lead plate; the anode one or more platinum wires, only the points of which are exposed to the liquid. Usually the length of point so exposed can be adjusted by means of a porcelain sleeve which surrounds each wire. For efficient working, the current must lie between certain limits. If the current is too small, mere ordinary electrolysis occurs; while if it is too great, the action is irregular, the anode hisses, becomes white-hot, and disintegrates rapidly. A noticeable feature of the interruption is the violet, or in some cases pinkish, glow which surrounds the platinum point when a suitable current is passing. The interruptions are accompanied also by an explosive and almost deafening noise.

Absolute agreement as to the theory of the working of the interrupter has not yet been attained. The general statement that the effect is due to the rythmic sealing and unsealing of the anode by the liberated gas obviously does not take account of all the circumstances. The size of the points, the current, the amount of self-inductance and capacity in the circuit, the concentration and temperature of the electrolyte are all factors influencing the interruptions. The following explanation, as given by Ludewig,* is somewhat more comprehensive. Immediately after the interruption of the current the gas begins to form irregularly on elevated parts of the electrode, while the current is conducted across those parts not covered by gas. As the parts of the electrode across which the current is conducted become smaller, the current density becomes very large, and the liquid at those parts is vaporised. It is well known that high resistance is offered to the passage of electricity from a smooth metal surface to a fluid. The vaporisation, then, is caused probably by the heat developed in overcoming this transitional resistance between the wire and the liquid, as well as the resistance of the electrolyte very close to the point. As this greatly increased resistance increases the amount of heat evolved for the instant, a portion of the vapour is dissociated into oxygen and hydrogen, and then the whole electrode is covered with an insulating sheath of an explosive mixture which completely interrupts the current. With the stopping of the current a high self-induced pressure is produced, which breaks down the dielectric gas layer by a spark, thus exploding the gaseous mixture. The excess of oxygen is driven off the electrode by the explosion, and the electrode again comes into contact with the liquid.

This type of interrupter was used in the research work referred to, partly on account of the fact that it needed little attention, and the discharge could be allowed to run continuously for hours, and partly because a large secondary current was required. When an adjustable sleeve is used over the anode, a perfect seal cannot be obtained between the wire and the porcelain insulation. Thus there is always a certain amount of current leakage—that is, current that passes uninterruptedly; and this tends to diminish the efficiency of the interrupter. In our case the electrode consisted of a small piece of platinum wire hermetically sealed through the end of a glass tube. Contact was made with the wire conveying the current by means of mercury covering the upper end of the platinum wire in the tube. Originally the wire was sealed into the tube by means of soft "flux" glass, and it was noticed that, after the discharge had been running for a short time, the glass round the wire became pitted out, a crater being formed with the wire projecting from its centre. A similar effect was observed with different kinds of glasses surrounding the metal wire. Thus, not only were clear, ruby, and white "enamel" flux glasses tested, but also German soda, new British soda, lead, and Jena glasses. The wire was sealed directly into these latter glasses by the Burnside process.* This is a cooling process, by means of which electrical conductors may be hermetically sealed into glass and other vitreous substances without the aid of any intermediate flux.

In all the glasses tested, this corrosive effect was observed, least of all, however, in the Jena glass. The resistive properties of Jena glass in other directions are, of course, well known. Photomicrographs are reproduced showing the platinum point projecting from the tip of the glass tube. The magnification in the various cases may be judged from the appearance of the wire, which was about 0.4 mm. in diameter. Fig. 1 shows the disruptive effect on German soda glass. Figs. 2 and 3 are two different photographs of the same piece of British soda glass, the former showing the edge of the crater with the wire projecting, the latter showing the rough base. Fig. 4 is of a piece of the same kind of glass, in which the crater-wall has broken down at one side. Slight devitrification of this glass took place during the sealing-in of the wire by means of the blow-pipe flame. This devitrification seemed to render the glass more liable to corrosion. A glance at the photographs will show that the pitting-out is not due to any action of a mechanical nature, as, for example, a water-hammer effect. Such an action would cause radial cracks and fractures; but these do not appear. Neither is the phenomenon due to the glass having been rendered brittle by the cooling during the sealing-in process, for flux glass which had been carefully annealed after the wire had been sealed into it readily showed the same effect. In no cases do the edges or the walls of the crater show a vitreous or conchoidal fracture, but roughnesses and irregularities appear. Fig. 5 shows a piece of Jena glass with two wires sealed into it. Fracture of the layer of glass between the wires might have occurred had the corrosion been the result simply of the Joule heating effect, or of the Peltier effect; but it will be noticed that there is no such fracture. The glass between the wires is quite unbroken, the pitting-out occurring almost uniformly round each wire.

It may be suggested that the action is stimulated by a species of electrolysis of the glass lying between the wire and the liquid. It is well known that glass may be readily electrolysed by quite moderate potentials if the temperature of the glass is raised. This electrolytic action consists of a transference of Na ions from the glass, SiO_2 being left behind. In certain cases the Na is replaced by the metal of the anode; but platinum cannot diffuse in this way into the glass. In the Wehnelt interrupter point electrode the corrosion takes place not only when the point is the anode, but also when it is the cathode. The formation round the wire near the point, of a layer of SiO_2, which would gradually crumble away, might explain the pitting-out action when the platinum is positive to the liquid; but this action would not take place when the current is in the reverse direction. Thus electrolysis does not account for all the facts.

The effect of changes in the temperature of the anode during the interruption must be considered. After using fusible alloys for points, McClenahan* stated that in the interruption stage the temperature never rose above 168 deg. Cent., and hence not high enough to produce incandescence, and that the light surrounding the point during interruption must be of the nature of a discharge of electricity through gases. This temperature seems rather a low estimate, for the interrupting action is undoubtedly caused by the intense heating due to the high current density about the small point. The spectra obtained from the light surrounding the point have been examined by Morse,† who used various metals in various electrolytes. His results suggest that the environment of the point passes through a great range of temperature with each interruption of the current, and that the high temperature is the cause of the luminescence. This high temperature, being local in its effect, might render the glass round the wire brittle and allow it to be disintegrated, and thus a crater would be formed. But the wide mouth of the crater and the appearance of the edges suggest that other factors also influence the action. The heat generated at the point vaporises and then dissociates the water in its immediate vicinity into hydrogen and oxygen. Spectra like those of the oxyhydrogen flame can be obtained from the explosion of the mixed gases by the hot metal in the cooler parts of the gaseous envelope. The presence thus evidenced of free hydrogen and oxygen at a temperature above the point of dissociation of water affords the possibility of a strong reducing or oxidising action on the metal forming the electrode and also on the glass. That the metal is exposed to this chemical action is shown by the fact that, when the wire used as electrode is of aluminium, calcium, barium or other metal having a strong affinity for oxygen, the spectra given by the light show the bands which are usually ascribed to the oxides of these metals. The glass also will undoubtedly be affected by the reducing action and become disintegrated, the metal constituents being precipitated or going into solution in the acid.

The ultra-violet rays of the light itself will further assist the action either directly, or indirectly by acting on the atmosphere in contact with the glass. The active nature of ultra-violet radiation is well known. Thus, glass exposed in air to ultra-violet light becomes coloured. This coloration is probably due to ultra-microscopic particles of reduced metal in the salt. Metals also, when covered

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

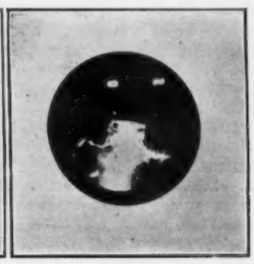


FIG. 5.

* *Ann. der Phys.*, vol. xxviii., page 175 (1909).

* *Electrician*, July 4, 1913; *Nature*, June 3, 1915.

* *Cf.* Compton, *Phys. Rev.*, vol. xxx., page 173 (1910).
† *Astrophysical Journal*, vol. xix., page 162.

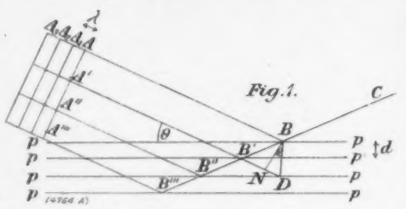
with a thin layer of water, corrode rapidly when subjected to the action of ultra-violet rays, this effect being caused by the ozone produced by the action of the rays on the water. It is probable that a similar effect is produced on the glass, and that this, as well as the other two factors referred to, plays a part in disintegrating the glass near the exposed point of the electrode wire and so producing the cavity.

RÖNTGEN RAYS AND CRYSTAL STRUCTURE.

To the general public the Röntgen rays remain the X-rays—the name chosen by their discoverer—a scientific mystery, more fascinating than radium, which, after all, does not do much more than shine and decay, a thing a conservative mind does not approve of. That in decaying radium generates helium, and that the disintegration proceeds through an extraordinary series of stages, ranging in time-period from minutes to thousands of years, is hardly understood by people who are quite able to appreciate the wonderful things that medical men have achieved with the aid of Röntgen tubes. But the rays have done much more. They have helped to establish the actual existence of the atom and to reveal that the atom itself has a structure, and they promise to disclose the structure of the atoms in crystals—*i.e.*, the way in which the atoms are grouped and arranged in solids. The student of elementary science soon grasps that solids are dreadfully complex by comparison with gases. The chemist can analyse solids as well as fluids. He splits a compound into its constituent elements, finds out the relative numbers of atoms of each constituent, counts, in conjunction with the physicist—for it is mainly physical chemistry, of course—the actual number of molecules or atoms, and assigns definite structures to the constitutions of certain substances. Those constitutions are not mere speculations; for compounds have synthetically been built up from their elements on the basis of these researches. But there science seemed to find its limit. Calcite, it has long been known, is $CaCO_3$, like limestone; in the kiln the carbonate behaves as if it were made up of CaO and CO_2; in solutions it seems to split into the ions Ca and CO_3. How are the atoms of Ca, C, O actually grouped in the crystal? If they were differently grouped, their properties would probably be different. What are the forces and the laws? The X-rays promise to answer these questions.

The X-rays first puzzled scientists by penetrating through opaque substances and by refusing to be reflected, refracted, or polarised. But there was a strong suspicion almost from the first that they were, after all, only rays of light, though of a light of extremely small wave-length, too delicate to be examined by ordinary apparatus. That assumption has been fully confirmed. The wave-length of sodium light is 5895×10^{-10} m., or Angström units (A.U.), or 5895×10^{-8} cm., and X-rays have wave-lengths of the order of 10^{-5} cm., about one ten-thousandth of the length of ordinary light waves. In a diffraction grating the spacings between the lines should be of the order of the wave-length of the incident light; that condition is fulfilled by ordinary gratings with about 20,000 lines to the inch. To rule a grating with 10,000 times as many lines would be out of the question; the distances between the lines should be of the order of inter-atomic distances. The ingenious idea occurred to Professor M. von Laue then (in 1912) at Munich (he accepted a call to Zürich soon afterwards) to make use of the ordered array of the atoms in a crystal as an X-ray grating. The experiments made by Laue in conjunction with W. Friedrich, P. Knipping, J. Herweg, E. Hupka and others, were surprisingly successful; crystals of zinc-blende, copper sulphide, rock salt, diamond, zinc, sulphur, &c., behaved like three-dimensional gratings. That was the origin of the new line of research. The experiments were made by letting a beam of Röntgen rays pass through a crystal on to a photographic plate; the black central spot produced on the plate was found surrounded by small dark spots of greater or smaller intensity, arranged symmetrically to the centre and lying on circles or ellipses passing through the centre, each spot representing a reinforcement of the waves in that direction. Crystals of copper sulphate gave such a radiograph, the powdered crystals did not. But long exposures (of many hours often) were required, and the interpretation of the radiographs in all their striking regularity, as given by Laue, was very complex; he published a memoir on the "Diffraction of Short Electromagnetic Waves by a Crystal" in the Berichte of the Bavarian Academy, Munich, June, 1912.

In a mathematical discussion of this memoir (Proceedings of the Cambridge Philosophical Society, February, 1913), Mr. W. Lawrence Bragg, of Cambridge, proposed a simpler interpretation of the phenomena, which he illustrated by the diagram, Fig. 1. Let a beam of homogeneous light A, A_1, A_2, A_3 of wave-length λ fall on a series of plane



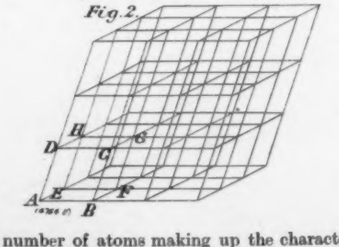
parallel surfaces p (all at the same distance apart d), each of which reflects a small proportion of the incident light and transmits the remainder; then reflection and interference will result as with thin films, except that there are a great many reflecting surfaces instead of the two of the soap film. The wave A B will partly be reflected, at its angle of incidence θ, in the direction B C, and will partly travel on into the crystal; this latter portion is not indicated in the diagram. The waves reflected at B^1, B^{11}, B^{111}, &c., will, under certain conditions, pass out in the same direction B C, and in the same phase. To find the conditions, draw B N at right angles to A^1, B^1 and produce A^1, B^1 until it cuts the plane B^{11} in D, which will be the mirror image of the point B in plane B^{11}; since then $B^1 B = B^1 D$, $A B = A^1 D$, and $N D = B^1 D$ (the distance by which the rays A B and $A^1 B^1$, and hence also the broken rays A B C and $A^1 B^1 C$, will differ) will be $2 d \sin \theta$. If D N be equal to the wave-length λ or to a multiple of it, the waves reflected at B and B^1 and similarly at B^{11}, &c., will all be in the same phase and reinforce one another. If D N differ only slightly from λ, the difference in phase will become greater and greater as the number of planes increases, and the resultant amplitude at C will practically be zero. Thus reflection (as different from ordinary reflection) will only take place when $\lambda = 2 d \sin \theta$. This will be a reflection of the first order, and to mark this we write $\lambda = 2 d \sin \theta_1$. If θ_1 be changed to θ_2, there will be again reflection of the second order for $2\lambda = 2 d \sin \theta_2$, and reflection of the third order for $2\lambda = 2 d \sin \theta_3$, &c. At angles not satisfying this condition there will be no reflection.

Now in a regular crystal the atoms are probably arranged in parallel planes p, thousands of planes, all at spacings d; the d may or may not be equal to the distance between two atoms next to one another in the same plane. The planes will not form continuous walls; that is not necessary for reflection, since a cluster of trees or a cloud can reflect sound waves as well nearly as a wall of rock. The atom-bearing planes are set in crystals at intervals of one or two Angström units. The characteristic X-rays used for this study are of the order of about half an Angström unit. This is a pregnant fact, to use the words of Professor W. H. Bragg; the wave-lengths might easily have been ten or a hundred times the atom spacings, and then the investigation of crystal structure by means of X-rays would have been impossible. The method suggested by Mr. Bragg has been applied with brilliant success by Mr. Bragg himself and by his father, Professor W. Henry Bragg, up till recently at Leeds, now at University College, London, and in this review we follow mainly the communications made by Professor Bragg, who quite recently lectured upon the subject again before the Institute of Metals and at the Royal Institution. The Bragg method, it may broadly be said, works with reflected rays, whilst the Laue experiments were with transmitted rays. In their main conclusions the two methods are in entire agreement.

The Bragg relation, $\lambda = 2 d \sin \theta$, may be utilised in two ways. When the λ is known, the θ are observed and the d determined; once the d values are determined, the λ can be checked. As the wave-lengths λ of X-rays have been measured by independent methods, and the θ can be measured within 1 minute of arc, the new research admits of considerable reliability. The apparatus used by Professor Bragg is a kind of spectrometer without lenses. A pencil of homogeneous X-rays from an anti-cathode of rhodium (or some other platinum metal) falls through two narrow slits on a crystal which is mounted on a platform; the reflected ray enters the slit of an ionisation chamber (about 5 cm. in diameter, 15 cm. long) charged with a heavy vapour (methyl bromide is now preferred, sulphur dioxide was first used); the resulting ionisation is measured by means of an electroscope and microscope. The crystal or the ionisation chamber, or both together, may be turned on the platform to determine the angles at which decided reflection and ionisation occur. There is always a slight diffuse reflection from the crystal surface; but the ionisation maxima are easily distinguished. As natural crystal faces are often rough or distorted, the crystals are sand-papered or etched with acid, or cleavage faces are taken; elaborate preparation is not required. The rays used are the characteristic rays of the anti-cathode; rhodium emits four such rays, or two pairs, the principal ray having a λ of 0.614 Angström unit; the principal ray of palladium has a $\lambda = 0.583$, of silver 0.557 A.U., the wave-length decreasing by about 5 per cent. as we pass from one atomic number to a higher number (Moseley). The ionisation curve found is really the spectrum curve of these characteristic rays; with a rhodium target, therefore, the rhodium rays are repeated in the spectra of higher orders at decreasing intensity; the amplitude of the curve marks the intensity. The method thus does not give any lasting records; the reflected beam might be received on photographic paper—M. de Broglie places a cylinder of sensitised paper round the crystal—but Professor Bragg rarely resorts to photography.

In order to elucidate the relation of the spacings to the crystal form, Professor Bragg calls attention to wall-paper patterns. The position of any point in a pattern may be fixed with regard to two arbitrary systems of parallel lines crossing one another and cutting the pattern up into a number of rectangles or parallelograms. But unless the chosen points of intersection are the same corresponding, representative points, repeating at regular intervals, the parallelogram will not be a "unit" comprising the *ensemble* of the pattern. Similarly the atoms of crystals are referred to "space-lattices," a kind of scaffolding of three-dimensional axes which, in the cubic system, cross all at right angles and at equal distances apart; in the other crystallographic systems the distances and angles are not all equal. When planes are passed through all the X, all the Y, and all the Z axes, the structure is cut up into cells, cubes, or parallelopipeds. Even the most complicated crystal can be referred to such a fundamental space-lattice as indicated in Fig. 2. But a cell will not necessarily be a fundamental unit, unless it compriss at least the

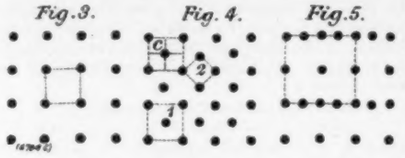
THE FUNDAMENTAL SPACE LATTICE



full number of atoms making up the characteristic molecule (possibly group of molecules) of the substance. Each unit can be considered separately; but to understand the growth of crystals and the special relations, it is better to consider the space-lattice as unlimited in all directions. In the crystal models the axes are represented by wires, and the

atoms by beads strung on them. Supposing the atoms to be spaced quite regularly, as in Fig. 3; each little dotted square (in the wall-paper), or each cube on that base (in the crystal), would represent a unit. In the alternating grouping of Fig. 4 each dotted square would again give a cube (1 or 2); but only one of the two (2) would represent a unit (the *c* in Fig. 4 will be explained presently); and in Fig. 5, four of the little squares would be required to

Fig. 3. *Fig. 4.* *Fig. 5.*



make up a unit. The relations become clearer when small balls (atoms) are piled upon one another, which can be done in various ways; but the wire models are the most instructive, and when they are so held in the lantern beam (as Professor Bragg does) that corresponding axes and atoms coincide, the arrangement of the atoms in the various planes can clearly be recognised.

When the pencil of X-rays falls on the plane A B C D (Fig. 2), the formula $\lambda = 2\ d \sin\theta$ gives the d as distance between that plane and the next parallel to it, E F G H. When the pencil falls on the plane A E H D, the distance of this plane from B F G C is determined. But planes may also be passed, *e.g.*, through E B C H and corresponding points, cutting off the bevel of the edge A D; again, the nose of the crystal may be cut off, as Professor Bragg calls it, by a plane through D and E B; and so on. The values of d determined in this way may or may not be equal; but they will always be in definite geometrical relations. The larger the angles of reflection observed the closer will be the spacing. Yet the deduction of the crystal structure from the d is not simple. In the case of a cubical lattice, for instance, the atoms may be arranged to cubes in three ways. When experimenting with rock salt (NaCl) and sylvine (KCl)—cubic crystals, very much alike in all properties—Mr. Bragg found that the d were not always in correspondence in the two crystals. There was parallelism when the atoms were referred: (*a*) to a simple cube (one atom at each corner), or (*b*) to a centred cube (one atom at each corner, one in the centre of the cube); but when the atoms were referred (*c*) to a face-centred cube (one atom at alternating cubic corners, one in the centre of a face, as in Fig. 4 (*c*), the analogy between rock salt and sylvine failed. This was found by considering cubic planes, planes bevelling off the edges, and planes cutting off the noses, as mentioned, and in this way it was established that KCl gives a simple cube of type (*a*), and NaCl a face-centred cube of type (*c*), whilst ammonium chloride is one of the rare examples of type (*b*). The face-centred cube (*c*) is very common, and the crystals of copper, silver, gold, &c., belong to this class.

So far all these measurements were merely relative, however. Absolute determinations of the d can be made when the atomic weight and the density of the material are known, and in the case of rock salt the distance between two planes (cubic faces) was found to be 2.81 A.U. The consideration of the relative intensities of the spectrum lines of the various orders constitutes another very important step. The intensity of a spectrum line depends upon the atomic weight of the atoms in the plane. When all the atoms in all the planes are the same, the intensities should diminish, according to a simple law, with the higher orders, just as in the case of a regular grating. That was found to hold for crystals of elements, and nearly to hold for KCl, because the atomic weights of K (39) and of Cl (35.5) do not differ much. But it did not hold for NaCl (Na = 23, Cl = 35.5). If the atoms of Na and of Cl were arranged in alternating parallel layers, the intensities should indeed alternate, just as in the case of a grating ruled with alternating strong and weak lines. Mr. Bragg correctly interpreted these features, and it follows that his value for the d of NaCl (above given), *i.e.*, 2.81 A.U., marks the distance between a sodium atom and the chloride atom next to it.

When the spacings between the parallel planes are not all the same, similar intensity variations should be observed. In the case of the diamond there is reason to assume that each carbon atom forms the centre of a small, regular tetrahedron, with carbon atoms at the four corners, from which it is equally distant; the lattice is a face-centred cube all the same. When the model is built up, it is seen that the first layer of atoms lies in the base, the second layer at the distance 1 above the first, the third layer at the distance 3 above the second, the fourth at distance 1 above the third, and so on. It is as if a grating were ruled with lines spaced 1 and 3 divisions apart alternately. Such a grating would not give any second-order spectrum, and the second-order spectrum of the diamond was indeed found absent. The structure of zinc-blende (Zn S) is exactly like that of the diamond; but there layers of Zn and S alternate at the distances 1 and 3, and as the atomic weight of sulphur (32.07) is only about half that of zinc (65.37), the second-order spectrum is weak, but not quite suppressed. The structure also would explain why zinc-blende has a polarity, whilst the diamond has not; for, with the atoms arranged in alternating planes of Zn and S, it would make a difference whether the light rays struck a zinc layer (coming from the left) or a sulphur layer (coming from the right). Professor Ogg, of the Cape, at present working at University College, has quite recently found that antimony and bismuth can be referred to tetrahedra, like the diamond; but the central atom is not equally distant from the others in their cases.

We will briefly notice some more complicated cases. Calcite crystallises in regular rhombohedra, which ought to be perfectly symmetrical about a certain plane. The X-ray examination shows that layers of Ca and of CO_3 alternate in certain parallel planes; in other directions layers of Ca, C, O, O succeed one another; the symmetry does not appear to be quite perfect, however; that is to say, the left and right half of a section only coincide when the one side has been slightly shifted (gliding symmetry). Dolomite, which is a double carbonate of calcium and magnesium, is found to be built up of layers of Ca, CO_3, Mg, CO_3, Ca, &c., and there is no plane of symmetry—which is in accordance with the views of crystallographers. The complicated structure of magnetite ($Fe_3O_4 = FeO.\ Fe_2O_3$) can be imitated by piling up layers of oxygen atoms and fitting iron atoms into the interstices; some of the iron atoms appear as centres of oxygen tetrahedrons (4 O atoms), in which the iron is bivalent, some as centres of octahedrons (6 atoms of O), in which the iron is tervalent; the two sets have some atoms in common and differ by 60 deg. in orientation.

Professor Bragg's wire models, which can be taken to pieces, also help us to understand a puzzling point. The X-ray examination seems to concern itself merely about atoms, and not to recognise molecules. The one Na molecule in rock salt might equally well belong to any one of the six Cl atoms near it. But it is difficult to say in what condition the molecule really exists in the solid, and the X-ray examination does not entirely lose sight of the molecule. The whole crystal behaves like a big multiple molecule. If, in taking the model to pieces, a definite order is observed, the complex crystals of magnetite, as well as the simple rock-salt cubes, break up into their molecules. That shows that there are various methods of breaking up a crystal, and that the surface of a crystal is more or less like an unsatisfied set of atoms, to which set arrangements of fresh atoms will easily attach themselves—an exceedingly fruitful conception, which would account for the growth of crystals as well as for surface adsorption.

When crystals are heated, the spacings between the atoms should widen, and the X-ray lines should be shifted and decrease in intensity; rock-salt crystals show this when heated in an electric furnace, while being examined. Similarly, the expansion of crystals in different directions could be determined with very small specimens; the method does not require large specimens. The new method may also disclose why soft metals form hard alloys; further, in which way the hard and soft state of metals of Beilby, the surface films and cement films between the crystals, differ from one another. E. A. Owen and G. G. Blake have studied hard and annealed copper by X-rays. The examination, of course, presupposes a regular arrangement such as crystals offer. Experiments with glass, which is not crystalline, have failed, we believe, as they were expected to do. On the other hand, O. Lehmann has applied Laue's method to the study of liquid crystals; F. Terada has examined rock salt in the plastic state; P. Knipping has discovered a structure in liquid and in solid paraffin and in wax, and S. Nishikawa and S. Ono (likewise experimenting after Laue) discern crystals in fibrous asbestos, arranged along the fibres, but not in glass threads.

In their main conclusions, the two methods, of Laue and of Bragg, are in essential accord with one another, as we have already stated, and that should be so according to L. Ornstein and others. The objections to the former method are the long exposure, the unavoidable (though, in a sense, useful) presence of X-rays of different frequency under these conditions, the difficulty or impossibility of making quantitative measurements, and the difficulty of interpreting the results; according to G. Friedel, moreover, Laue's method does not bring out the full hemihedral symmetry. The quantitative ionisation measurements (though not so accurate as the angle measurements) and the rapid working with homogeneous rays are the advantages of Bragg's method; the constancy of the radiation frequency can be checked by the comparison of the intensities of the different order spectra. Absorption, studied by C. G. Darwin, plays a part in both methods. It is satisfactory that Glocker agrees with W. L. Bragg and his co-workers as to NaCl and KCl; with A. Johnsen as to calcite; with E. Keller as to the diamond, and with P. P. Ewald and Friedrich as to zinc-blende, though not as to pyrites. On the other hand, F. M. Jaeger maintains that the theory is so far inadequate, on either lines, to deal with biaxial crystals; there is still one factor missing in the deductions.

X-ray investigation of crystals is young, of course. But there is a dearth of workers, and the war has cruelly put an end to the life of some investigators and has interrupted the work of others. Mr. H. G. J. Moseley was killed in the Dardanelles, Mr. S. E. Pierce in France; there may be other victims. M. de Broglie, who has tried both methods and modified them, attended one of Professor Bragg's recent lectures in the uniform of a French medical officer. Mr. W. L. Bragg has gone to the Front. It was pathetic to hear Professor Bragg mention this at the Institute of Metals, lest credit be given to himself that was due to his son. Professor Bragg has already lost one son in the war.

ON REDUCTION GEARS.

By JOHN H. MACALPINE.

(*Continued from page* 492.)

Interpretation of the Power Constant.—Let us return to the Table of Gear Data and notes. Among rigid gear results the power constant of the Vespasian is fairly high, but (Note I) this is a progressive trial-trip value of short duration, far above that for service speed. The power constants for the Tuscania and for the Ciudad de Buenos Aires and her sister-ship were also trial-trip results (Notes J and K). In no case, then, does the value of the power constant in daily use with rigid gears appear to approach the values 3.5 and 4 commonly attained with floating-frame gears at frequent intervals and over considerable periods. In the trials of the Neptune's present gears we have promise of still higher results, which it may be found quite safe to use when experience has shown the best ratio of h/D and the best number and design of teeth. The anticipation of a largely increased value was what led to our introduction of the floating frame when we found how completely it took away the extreme delicacy of alignment of the rigid gear and still more when its effect on torsion—not so important as that on alignment, but still of great value—was noticed. My own anticipation was that it would be possible to raise the power constant to over two, and possibly to three, times its value for a rigid gear without exceeding the same maximum intensity of stresses. Experience has in no way altered this belief. It can hardly fail that during

its service a rigid gear with power constant 2 will, through wear or accidental changes of adjustment, experience much more intense, because localised, stresses than a floating-frame gear with a power constant 4. Examination of Fig. 6 (see page 479 *ante*) shows that a very slight accident may intensely localise the stresses.

This great rise of stress will become evident if we consider a particular case: in Fig. 3, page 456, when everything is in exact adjustment, if we neglect the torsional and other errors, the teeth of helix H_1 will bear uniformly from a to b. Suppose now, without changing the pinion speed or the power transmitted, that by very slight disturbance of the alignment the contact is reduced till the teeth bear from a only half way to b. The bearing will be hardest at a and taper off to zero at the middle of the helix; but, as the total tooth pressure is unchanged, the intensity of bearing at a must obviously be about four times that for the pinion in exact adjustment. Similarly, if the bearing is reduced to one-third of the length, the maximum intensity is increased about six times, and so on.

In this connection I may quote from Mr. G. White, B.Sc. (Lond.), in a chapter on "Helical Gearing": "To obtain the finest results one of the pair of wheels—the smaller one for convenience—should be permitted a little automatic axial movement, and also a rocking movement about a fulcrum in the central plane of the wheel."* Experience has shown to other engineers the great importance and also the great difficulty of keeping the pinion in exact alignment.

The range of application and the advantage of reduction gears rise rapidly with the power constant. In rolling-mills there have long been reduction gears, the teeth having a pitch of 9 in. or 12 in., or perhaps more, transmitting large powers. But their power constants are small and it would be utterly impossible to apply them to turbine drives or instal them on board ship. Not only would the pitch-line speed be enormous—possibly exceeding the allowable value, of which we are yet ignorant—but neither could the space be allowed on shipboard nor the great weight.

In two similar gears the total weight is proportional to the cube of the linear dimensions—that is, to D^3; or

$$\text{Weight} = K D^3.$$

From equation (1) we have

$$\text{Weight} = W = K D^3 = \frac{1000 K P}{C R} \quad . \quad (10)$$

Hence, in applying a reduction gear to a turbine of given power and speed (P and R constant) the weight of the reduction gear is inversely proportional to the power constant.

If the gears are of different type, we must allow for those parts which are peculiar to each. Thus in comparing a rigid gear with a floating-frame gear the extra weight of the floating frame and increase of bed-plate required must be added In the experimental gear these weights formed about 17.5 per cent. of the whole, but this was only a 5 to 1 reduction. The percentage quickly decreases as the ratio of reduction increases. Thus on a 15 to 1 reduction it is only about 6 per cent.

In taking advantage of the increased power constant we may either keep the speeds of pinion and gear the same, decreasing the weight and to some extent the space required for the reduction gear; or, leaving the large gear of the same diameter, we may reduce the pinion and increase the speed of the turbine, with saving in its weight and usually increasing its economy; or we may follow some middle course.

Equation (10) states also that if we compare two similar reduction gears which have the same speed of pinion R and power constant, the weight per horse-power, W/P, is the same for each. Frequently, however, the larger reduction gear would run more slowly, and if the pitch-line speed is constant the weight per horse-power will be proportional to the linear dimensions.† This corresponds to the well-known proposition that in similar engines (steam or gas, &c.) working at the same pressure and running at the same piston speed, the weight per horse-power is proportional to the linear dimensions, and the intensity of stress at each corresponding point is the same for similar configurations. This proposition regarding reduction gears, as well as that for engines, is true whether inertia stresses are included or not.

* "Toothed Gearing," page 90, by Geo. T. White, B.Sc. (Lond.). London: Scott, Greenwood and Son. 1912.

† Re-writing equation (10),

$$\frac{W}{P} = \frac{1000 K}{C D R} \times D = \text{const.} \times D,$$

if D R is constant.

THE TEETH.

(*a*) *The Helical Angle.*—Although it is well-known that the intensity of pressure on helical teeth does not change sensibly with the angle θ of the helix, I will, for clearness, give the proof. In Fig. 8, $a\ b$ is a portion of the pinion axis, and $d\ e$, $d^1\ e^1$, are projections of portions of the lines of contact of two consecutive teeth at the instant for which the figure is drawn Examination of Fig. 5 shows that this very closely follows the projections of the pitch-lines; for, as the tooth passes from γ contact to a contact the intersection of the tooth front with A B and its intersection with the pitch-line are always nearly at the same distance from C C_1. We may then, without sensible error and with great simplification, treat $d\ e$ and $d^1\ e^1$ as projections of portions of the pitch-lines and put

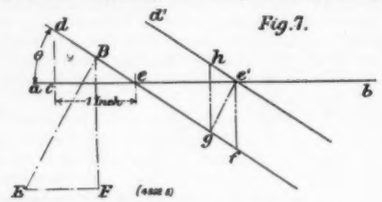


Fig. 7.

angle $d\ e\ a = \theta$. Also, for simplicity of statement, suppose the pinion very large, so that we may represent $d\ e$ as a straight line and $c\ e$, its projection on $a\ b$, as 1 in. long. B E is the whole force on $d\ e$ tangent to the pitch surface and, neglecting friction, d B E is a right angle. B F is the component of B E normal, and F E that parallel, to the axis. As the movement of the tooth is normal to the axis $a\ b$, B F alone transmits power. Hence for the same power and speed B F must be constant whatever the value of θ. Therefore, if we had spur-teeth ($\theta = 0$), B F would be the intensity per inch on one tooth when passing the pitch-line.

Let

$$\text{B F} = q.$$

Then

$$\text{B E} = q \sec. \theta.$$

Also,

$$d\ e = c\ e \sec. \theta = \sec. \theta, \text{ since } c\ e = 1.$$

Therefore the intensity of normal pressure on the tooth $= \dfrac{\text{B E}}{d\ e} = q$, for all values of θ.

Hence, in determining the intensity of pressure on the teeth, we take no account of the helical angle θ.

Again, $e^1\ f$ being the circumferential pitch and $e^1\ g$ the normal pitch,

$$e^1\ g = e^1\ f \cos \theta \quad . \quad . \quad . \quad (11)$$

The thickness of the tooth at the pitch-line is usually a little less than half the normal pitch. To maintain a constant proportion of thickness to pitch the proportions of the hob would, of course, have to change with θ. (In the experimental gear, Fig. 5, the thickness of pinion tooth was rather greater than half the pitch, to allow for greater wear of the pinion teeth than of the gear teeth; but this allowance is hardly necessary, as wear is found to be so minute.) If ρ is the circumferential pitch and t the thickness of the tooth, equation (11) gives:—

$$t = a \rho \cos \theta \quad . \quad . \quad . \quad . \quad (12)$$

As above, if t is the thickness at the pitch-line, a = about 0.5; if it is the thickness at the root, a is greater.

Consider pinions of a given diameter and number of teeth (having therefore the same circumferential pitch) but different values of θ; also suppose the normal section, such as shown in Fig. 5, to be the same for all, so that the addenda and dedenda are unchanged, and the leverages for cross-bending forces, of constant intensity q, are practically unchanged. The intensity of cross-breaking stress at each point, say at the roots, will be proportional to t^{-2} and the elastic yields to t^{-3}; that is, from equation (12):—

$$\text{Strength of tooth} = a_1 \cos^2 \theta \quad . \quad . \quad . \quad . \quad (13)$$

$$\text{Elastic yield} = a_2 \sec^3 \theta \quad . \quad . \quad . \quad . \quad (14)$$

where a_1 and a_2 are constants.

Equation (14) gives the elastic yield normal to the teeth. Changing the meaning of Fig. 7 for the moment, suppose $d\ e\ f$ gives the unstrained position of a portion of a tooth and $d^1\ e^1$ the strained position of the same tooth, equation (14) represents the yield $g\ e^1$. But measured circumferentially the elastic yield is $g\ h$.

$$\therefore \text{ Elastic yield measured circumferentially} = a_3 \sec^4 \theta \quad . \quad . \quad . \quad . \quad (15)$$

where a_3 is a constant. This is the yield which should be considered, as the rotational movement of the tooth is parallel to $g\ h$.

When considering the value of θ which should be adopted in the experimental gear it seemed certain that $\theta = 10$ deg. would give ample forces E F to determine the longitudinal position of the pinion, but it would give rather a small number of teeth in action at one time, thus tending to make the gear noisy. By adopting $\theta = 30$ deg. the number of teeth in action on each helix, since $h = 20$ and circumferential pitch $= 1\frac{1}{4}$ in., is:—

$$\frac{20 \tan 30 \text{ deg.}}{1.25} = 9.24.$$

Compared with a spur-gear for which $\cos \theta = 1$, the strength, equation (13), is reduced in the proportion $\cos^2 30$ deg. $= 0.75$, and the elasticity, equation (15), increased in the proportion $\sec^4 30$ deg. $= 1.78$. There seemed to be sufficient teeth in mesh to assure reasonable quietness; strength was not too greatly sacrificed, and at the highest power we hoped to reach there was a large factor of safety, even if the pressure was not very uniformly distributed; the desired elasticity was very sensibly increased. $\theta = 30$ deg. has always been retained. The gears are very quiet, which bears evidence to the floating frame performing its functions admirably; in fact, the Westinghouse Machine Company satisfactorily executed one order in which it was specified that the gear should be silent.

In the rigid gears of the Vespasian $\theta = 20$ deg., but in subsequent rigid gears θ seems to have usually been increased to about 45 deg. I understand that this change was made to produce a quieter running gear. Comparing the strengths of tooth for $\theta = 30$ deg. and 45 deg. we have:—

$$\frac{\cos^2 30 \text{ deg.}}{\cos^2 45 \text{ deg.}} = 1.50.$$

Thus, considering the strength of the teeth only, without regarding more even distribution of pressure, a rise of 50 per cent. in the power factor is accounted for.

The elasticity is increased for $\theta = 45$ deg. over that for 30 deg. in the ratio:—

$$\frac{\text{sec.}^4 45 \text{ deg.}}{\text{sec.}^4 30 \text{ deg.}} = 2.25,$$

but that is very far indeed from compensating for the enormous ratio of the ordinates of curves A C, A B, Fig. 6, for a given gauge error.

If, as is likely, the increase to $\theta = 45$ deg. is accompanied by a decrease of the addenda and dedenda, the leverages for cross-breaking are diminished; but the arc of contact is also restricted, increasing the intensity of pressure of the teeth in contact, and the elastic yield is much restricted, leaving little, if any, advantage from the increase of θ.

(*b*) *Number of Teeth.*—From Proposition C it at once follows that the best design of pinion will have teeth of certain fixed proportions and a definite number, but experience so far seems to have shed little light on what is the best number to adopt. It seems not improbable that there is a considerable range within which the change of advantage is not great. Let us suppose a series of pinions of the same pitch diameter and length of helix, but increasing number of teeth. Let the helical angle θ and the angle of obliquity ϕ be the same for all and also the ratios of thickness, addendum, and dedendum to pitch. *If the arc of contact remained constant*, the total length of contact would be pro-

NORTH-EASTERN RAILWAY ELECTRIFICATION.

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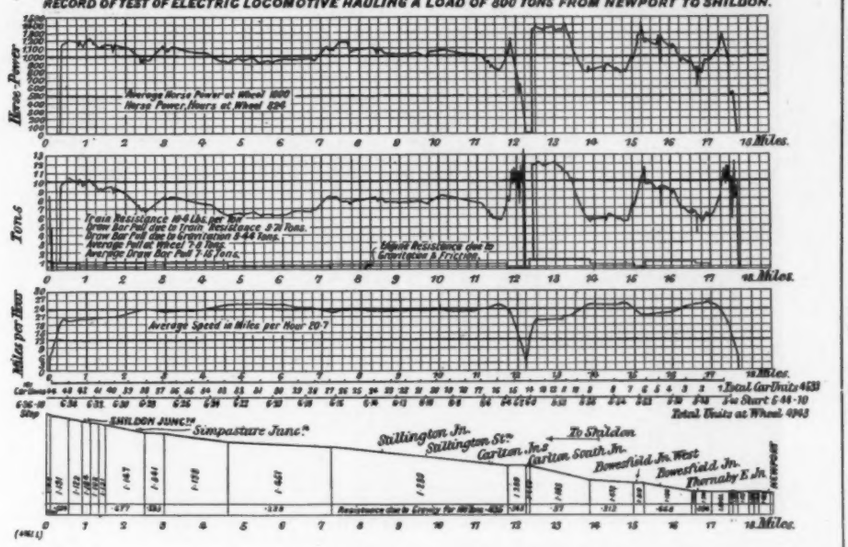
Fig. 32. ELECTRIFICATION OF SHILDON-NEWPORT MINERAL LINE.
RECORD OF TEST OF ELECTRIC LOCOMOTIVE HAULING A LOAD OF 800 TONS FROM NEWPORT TO SHILDON.



portional to the number of teeth. As the total pressure is the same, the pressure per inch would be inversely as the number of teeth—that is, it would be directly proportional to the pitch. This, I have shown, is what Proposition B demands. But the arc of contact will *increase with the pitch*, and while it is not doubled (as we may readily see by sketching on Fig. 5) by doubling the pitch, it does not fall far short of this. Hence, as we pass to pinions of fewer to those with more teeth, the intensity of internal, or fibre, stress rises almost in proportion to the number of teeth. Also, by Proposition B, the yield per unit fibre stress in the small teeth is proportional to the pitch. So far the advantage lies entirely with the greater pitch.

But as we continue to increase the pitch we soon get to proportions which would produce interference, and to avoid this we must either increase the angle of obliquity ϕ or decrease the addendum of the large gear. Both courses restrict the arc of contact and thus cause an increase of intensity of tooth pressure. It is important also to notice that the larger pitch and addendum requires that the pinion be more deeply cut into within the pitch surface. This will weaken the pinion against resisting torsion, as it is well known that such projections as teeth contribute little to torsional rigidity. This will in turn restrict the helix length h which could advantageously be used and thereby further increase the stress on the teeth. (The flexural rigidity is little affected, as the teeth strongly contribute to this, and the extra metal cut away under the pitch surface as the pitch increases is compensated by the increased addendum.) Thus we see that there is an upper and lower limit of the number of teeth.

The circumferential pitch of the experimental gear is $1\frac{1}{4}$ in., the pinion has 35 teeth and the large gear 176 teeth, giving, as we should always do, a hunting tooth. The angle of obliquity as designed is 14 deg. 30 min.* The addendum of the large gear was made so as to sufficiently avoid interference. The addenda of the gear and pinion give an arc of contact of $2\frac{3}{4}$ in., a little over twice the pitch, divided equally by the line of centres C C_1, thus reducing the mean speed of sliding of the teeth to a minimum. This was intended to reduce friction and wear, but I question now if it is of much importance.

The pinions having the smallest number of teeth, in the Table of Gear Data, are that for the Vespasian, 20 teeth, and that for the cruising gears for the U.S.S. Arizona, 21 teeth. The practice followed in all cases by the Westinghouse Machine Company is to use a hob with an obliquity of 14 deg. 30 min. and reduce slightly the addendum of the large gear to avoid interference. This gives $\phi = 16$ deg. 38 min., as in the preceding footnote, and divides somewhat unequally the arc of contact, the arc traversed when the teeth are approaching CC_1, Fig. 5, being shorter than that when they are leaving it Reducing this addendum has the advantage of allowing the diameter of the pinion at the root of the teeth to be kept up, thereby retaining as much torsional rigidity as possible.

I question if experience will lead to improvement of this practice and I will accept this value of ϕ and the reduced large-gear addendum as settled in what follows.

My own conclusion after the trials of the experimental gear was that the number of teeth should not be reduced below 30, but that was to avoid interference without cutting down the addendum of the large gear. Even now I would be unwilling to reduce below 25 teeth.

(*c*) *Pressure on Teeth.*—Near the beginning of this paper I stated: "I hope to show that consideration based on elementary principles leads to a simplification of the problem; and the reduction of the number of variables will make it easier to deduce from experience correct values of the constants involved." I think the truth of this statement will now be admitted. By observing the power constant safely borne by gears in service we will gradually reach approximately the best value of the two independent variables, the helix ratio, h/D, and the number of teeth. No absolute best values for these two quantities will be found, for when at the top of a fairly rounded hill a short movement to east or west, or again to north or south, which movements are two independent variables, make little difference in our height. Similarly, if we knew the best values of h/D and the number of teeth, a small change in either or both would make little difference in the safe value of the power constant. (I think it would be a little safer to be rather under than over the best value in both cases.) Close approximations to the best values should therefore not be difficult to reach. Then everything is settled and the question of the pressure on the teeth is determined for all pitches; indeed tooth pressure then becomes a question of quite secondary interest. From equation (1)

$$P = \frac{C\,D^3\,R}{1000}.$$

Also

$$P = \frac{\pi\,D\,R\,p\,(2\,h)}{12 \times 33{,}000}.$$

Let us take $h/D = 2$, approximately its value in most of the floating-frame gears in the Table of Gear Data, though I believe its best value may be slightly under this. The equations give:—

$$p = 31.51\,C\,D.$$

We need only calculate for one value of C and 1 in. pitch, as p is simply proportional to each. It will be instructive to use both 25 and 30 teeth.

Pitch. in.	C.	No. of Teeth.	D. in.	p. lb.
1	4	25	$\frac{25}{\pi} = 7.958$	1003
1	4	30	$\frac{30}{\pi} = 9.549$	1204

In both cases the value of p is considerably over twice that assigned by Messrs. McLaren and Welsh for the corresponding value of D.

The intensity of pressure on one tooth will vary with its position in the arc of contact, and if the arc of contact is two pitches, the above values of d are twice the mean value of this pressure.

(*To be continued.*)

* As already stated, I found that the hob had been given an angle of obliquity of 14 deg. 30 min., and thus the angle of obliquity in the normal section, Fig. 5, was increased to $\phi = 16$ deg. 38 min. By a simple proposition in solid geometry, if ϕ' is the angle of obliquity of the hob and θ the helical angle,

$$\tan \phi = \tan \phi' \sec \theta.$$

ELECTRIFICATION OF SHILDON-NEWPORT BRANCH, NORTH-EASTERN RAILWAY.

(*Concluded from page* 500.)

As can be seen from Fig. 26 of Plate XLV., published last week, louvred openings are fitted at each end of the locomotive, providing natural ventilation for the resistances through rain-proof air-vents on the top of the sloping ends.

The main automatic circuit-breaker is fitted on the roof of the cab and controls the current to the traction motors. This circuit-breaker is fitted with horned spark-gaps which project through the roof of the cab, as was shown in Fig. 24, Plate XLV. The circuit-breaker is operated either by means of the set-and-trip switch on the master controllers as mentioned, or by means of a mechanical hand trip fitted on the circuit-breaker case. The circuit-breaker, however, can only be closed by the set-and-trip switch on the master controller. Red and green lamps are provided to indicate whether the circuit-breaker is set or tripped. An illuminated dial ammeter is provided at each end of the cab in front of the driver. As mentioned above, two independent dynamotors are fitted in the cab of each locomotive. The armatures of these machines are double wound and fitted with two commutators, the commutators being connected in series across the full-line voltage. The control circuit is tapped off between the centre point and earth, so that current is obtained for these circuits at approximately half-line voltage. The actual voltage when supplying the control circuits and about 1 kw. for lighting is about 710 volts. The speed is 1500 revolutions per minute. The shaft of each dynamotor is extended and fitted with a fan, each fan supplying ventilating air to the pair of main motors on one bogie. The rated continuous output with a 50 deg. Cent. temperature rise is 4.5 kw. Each dynamotor is controlled by an ironclad circuit-breaker and a no-arc fuse. A starting resistance is in circuit with each machine, this resistance being automatically short-circuited by a relay a few seconds after the circuit-breaker is closed.

A motor-driven air-compressor is fitted in the cab of each locomotive for supplying air for the Westinghouse brake equipment, air sanding, raising the bow collectors and for air-whistles. The machine is capable of dealing with 50 cub. ft. of free air per minute and of raising this to 100 lb. pressure per sq. in.

The machine is run at full line voltage and is coupled direct in the circuit of the collector bows on the line side of the main circuit-breaker, so that immediately on the bows being raised by the hand pump, as described later, the compressor starts up, pumping the air in the reservoir up to full working pressure. It is controlled by an automatic circuit-breaker similar to those controlling the dynamotor circuits, a starting resistance being provided and short-circuited by an automatic relay in the same manner; but in this case the relay is fitted with a time-limit arrangement to extend the starting time.

An automatic governor is provided for the compressor and is so arranged that the motor circuit is opened when the air pressure rises to 100 lb. per sq. in., and closes again when the pressure falls to 80 lb. per sq. in.

Two bow collectors are provided on each locomotive. These can be seen in position on the roof of the cab in Fig. 21, Plate XLIV. *ante*. Each collector consists of a hinged pantograph built up of steel tubing, the whole being supported off the cab structure by strong corrugated insulators. Fig. 13, page 498 *ante*, shows a general view of the top of the cab, showing both bow collectors in position, one being collapsed, the other raised to the full extent. Each collector has two bows, each fitted with an aluminium rubbing strip, making contact with the

overhead contact wire. There are thus four rubbing strips per locomotive, which, with the double-contact wire, makes eight points of contact. Each of the two collector bows on a pantograph is attached to it by two separate leaf springs, so that they provide for any small irregularities in the level of the contact wire independently of the vertical movement of the pantograph itself. A hand pump is provided, by means of which the bows are raised at the commencement of the day's working, if no pressure is available in the reservoir. By means of the control cocks in the cab, either one or both of the bows can be raised or lowered. Each pantograph is raised and maintained in contact with the overhead wire by means of an air cylinder, so that in the event of a failure of the air pressure, the bows are automatically lowered. The air cylinders raise the pantographs through springs, which can be seen in Fig. 13, and which maintain an even pressure against the contact wire notwithstanding variations in its height.

TESTS OF ELECTRIC LOCOMOTIVE.

Tests have been carried out recently with one of the electric locomotives. Several journeys were made between Shildon and Newport, a train of 1400 tons of laden wagons being taken down from Shildon to Newport, and a train of 800 tons, consisting of 92 empty wagons, hauled from Newport up to Shildon, with stops on certain of the heaviest grades. The 800-ton train was stopped and started on a grade of 1 in 103. The maximum draw bar pull during the tests reached 16 tons, the average speed on the run up from Newport to Shildon being 18.3 miles per hour, the maximum speed being 26 miles per hour. Up a grade of 1 in 230, which is 4½ miles long, the 800 tons load of empty wagons was hauled at an average speed of 23 miles per hour. The locomotive also proved capable of hauling the 1400-ton train on the level at 26 miles per hour. The general operation of the locomotive proved satisfactory in all respects throughout the test. The results of these have been plotted as curves in Fig. 32, page 521.

An existing engine shed at Shildon was adapted for the use of these locomotives, a sufficient portion being electrically equipped for the purpose. An automatic circuit-breaker is provided controlling the whole of the shed equipment, and each engine stall is controlled by an independent isolating and earthing switch, so that work can be safely carried out on the roof of any locomotive without interfering with the operation of locomotives in adjacent stalls.

Sub-Stations.—As will be seen from Fig. 1, page 496 *ante*, there are two rotary converter sub-stations converting the 3-phase high-tension current as received from the power companies' systems to direct current at 1500 volts for the overhead track.

Both the sub-stations are similar in outside appearance. The sub-station at Aycliffe contains two 800-kw. rotary sets, each set consisting of two 400-kw. rotary converters in series.

Fig. 33, annexed, shows a general view of the interior of the sub-station in which a portion of the high-tension A.C. switchboard can be seen, and Fig. 34 gives a view of the D.C. switchboard.

It will be noticed in Fig. 33 that, this being a high-tension sub-station, the machines are enclosed by expanded metal screens. The rotary converters were built by the British Thomson-Houston Company, Limited, the transformers being of the British Westinghouse Company's make. The rotaries are of the self-synchronising type, and are started by oil-immersed drum-type starting switches. The Erimus sub-station is generally similar, and two rotary sets are also fitted, but in this case one is of 1200 kw. capacity. Two auxiliary transformers are installed in each sub-station, connected directly across the high-tension terminals of the main transformers.

A feature of interest in connection with these is the fact that they were fitted with a double secondary winding, one section being used exclusively for metering and the other for supplying lighting and auxiliary power in the station for portable air-compressors, &c.

The sub-stations are supplied with three-phase current from the interconnected main system of the North-East Coast Power Companies through the Cleveland and Durham Electric Power Company. Aycliffe is supplied at a pressure of 20,000 volts between phases through two overhead lines. The 20,000-volt switch gear is of the Reyrolle ironclad wall operated type.

The Erimus sub-station is supplied at a pressure of 11,000 volts between phases through underground cables connected to the power company's system in the Middlesbrough district, the alternating-current switch-gear being of the same type as that of Aycliffe. The direct-current switch-gear at both sub-stations is of the brick-cell type. Fig. 35, page 523, shows a diagram of connections of Aycliffe sub-station.

Each sub-station is connected to the overhead track wires by four positive feeders, consisting of paper-insulated bitumen-sheathed single-wire armoured cables, each of 0.5 sq. in. section, laid in wood troughing run in with bitumen.

There are two negative cables at each sub-station connecting the track rails to the negative busbar, these cables being similar in size and type to those used on the positive side. A hand-operated travelling crane is fitted in each sub-station.

The following is a list of the firms responsible for carrying out the work:—

Locomotives.—North-Eastern Railway Company, Darlington.

Overhead Track Equipment and Electrical Equipment for Locomotives.—Siemens Brothers Dynamo Works, Limited, Stafford.

Architect for the Sub-Station Buildings.—Mr. Arthur Pollard, architect to the North-Eastern Railway Company, York.

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FIG. 33. INTERIOR OF SUB-STATION AT AYCLIFFE.

FIG. 34. DIRECT CURRENT SWITCHBOARD AT AYCLIFFE SUB-STATION.

Steelwork and Brickwork for the Sub-Station Buildings.—R. Blackett and Son, Building Contractors, Darlington.

Sub-Station Plant.—The British Thomson-Houston Company, Limited, Rugby. Sub-contractors for the High-tension Switch-gear, Messrs. A. Reyrolle and Co., Limited, Hebburn-on-Tyne Sub-contractors for the Static Transformers for the Rotary Converters, the British Westinghouse Electric and Manufacturing Company, Limited, Manchester.

Cranes in Sub-Stations.—Herbert Morris, Limited, Loughbrough.

20,000 and 11,000-Volt Overhead Transmission Lines and Cables supplying the Sub-Stations.—The British Insulated and Helsby Cables, Limited, Prescot.

We are indebted to the British Thomson-Houston Company, Limited, Rugby, for the following additional notes on the sub-station plant:—

The track is fed by two sub-stations, one at Erimus and the other at Aycliffe. Longitudinal and transverse cross-sections of these sub-stations are represented in Figs. 36 and 37, Plate XLVI., whilst a ground plan is shown by Fig. 38, and a plan of the basement, showing how the mains enter and leave the station, is given in Fig. 39. The supply is three-phase, the high-tension voltage being 20,000 at Aycliffe and 11,000 at Erimus. This had to be converted into direct current at 1500 volts, and several methods of conversion presented themselves. It was decided to instal rotary converters on account of their high efficiency and large overload capacity. It was then necessary to decide whether the 1500 volts should be generated in the armature of a single rotary or by connecting two rotary converters together in series to form one unit. The scheme of connecting two rotary converters in series to generate 1500 volts was that eventually adopted, as it enabled the machines to be designed with a reasonable commutator speed and a very conservative value of voltage between commutator bars. Three 800-kw. units were installed, two at Aycliffe and one at Erimus, each consisting of two 400-kw. 800 revolutions per minute, 750-volt, 40-cycle, six-phase commutating-pole rotaries, connected in series to generate 1500 volts. A general view of one of these converters is reproduced in Fig. 45, page 524. The machines were designed and tested to operate normally at 95 per cent. leading power factor, and to withstand an overload of 50 per cent. for two hours, 100 per cent. for 10 minutes, and 200 per

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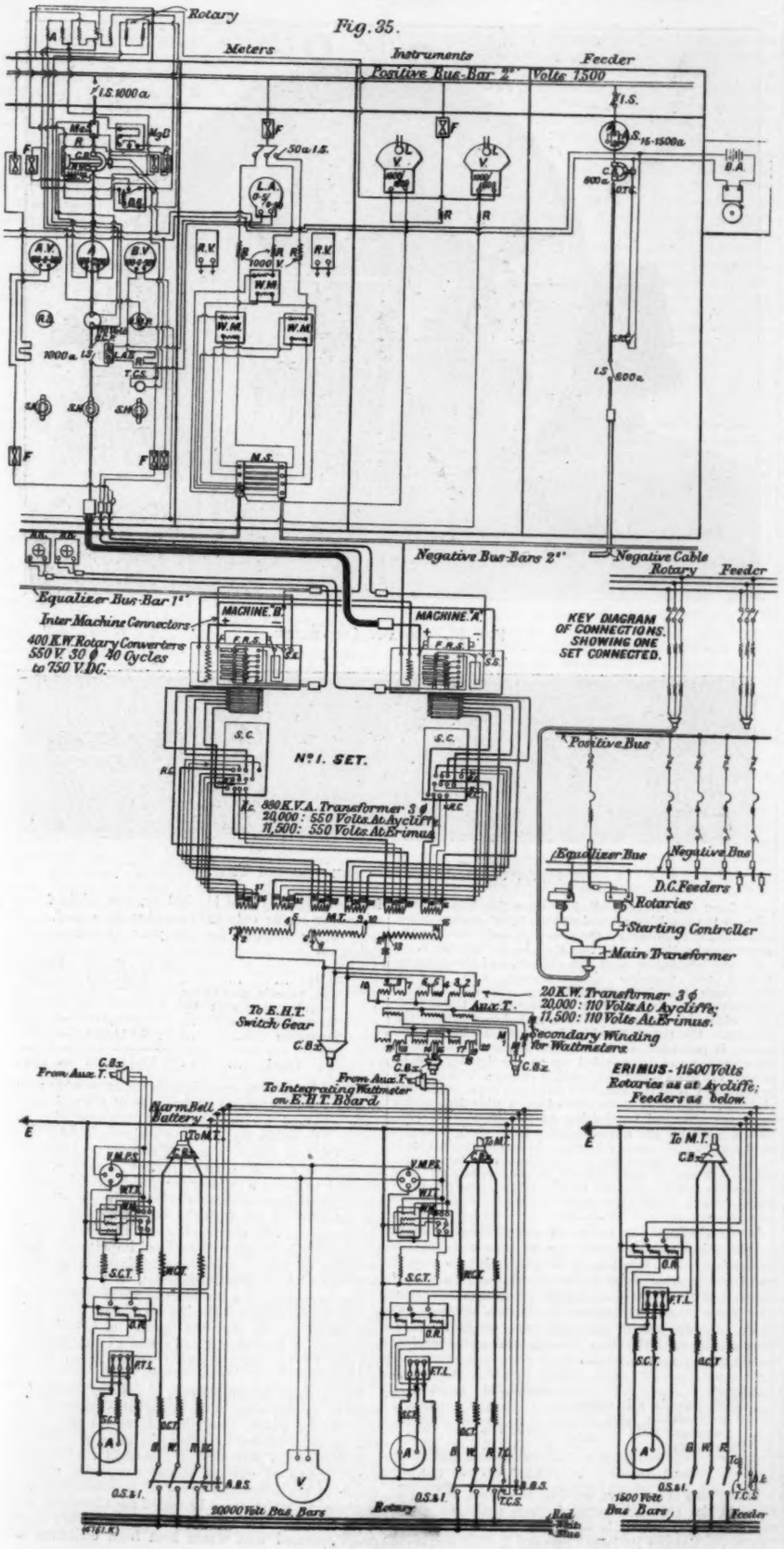

TABLE I.

REFERENCES FOR FIG. 35.

880 *Kv.-A. Transformers; Table of Voltages.*

Aycliffe.	Erimus.	—	550 Volts Across.	338 Volts Across.	185 Volts Across.
volts	volts				
20,000	11,500	Across 1-6-11 with 5-10-15 neutral give	16-19	16-18	16-17
19,450	11,250	Across 2-7-12 with 5-10-15 neutral give	24-27	24-26	24-25
18,900	11,000	Across 3-8-13 with 5-10-15 neutral give	32-35	32-34	32-33
18,500	10,750	Across 2-7-12 with 4-9-14 neutral give	20-23	20-22	20-21
18,000	10,500	Across 3-8-13 with 4-9-14 neutral give	28-31	28-30	28-29
—	—	—	36-39	36-38	36-37

20 *Kv.-A. Transformers; Table of Voltages.*

Aycliffe—

	Volts.
20,000 volts across 1-4-7 with 2-3, 5-6, 8-9 joined give	130.5 across 11-14-17
	110 " 12-15-18
	18.7 " 13-16-19

Erimus—

	Volts.
11,000 volts across 1-4-7 with 1-2, 4-5, 7-8, 8-6, 9-10 joined give	130.5 across 11-14-17
	110 " 12-15-18
	98.7 " 13-16-19

With either of the above connections, M_1, M_2, M_3, 110 volts are obtained across meter windings.

APPARATUS.

A.	Ammeter.	S.H.	Switch-handle.
V.	Volt-meter.	I.S.H.	Isolating switch-handle.
F.	Fuses.	S.P.S.	Single-pole switch.
I.S.	Isolating switches.	T.L.F.	Time-limit fuses.
R.	Resistances.	V.M.P.	Volt-meter plug.
O.S & I.	Oil-switch & isolators	M.T.	Main transformer.
S.C.	Starting-controller.	Aux.T.	Auxiliary transformers.
W.M.	Watt-meters.	L.	Lamp.
E.	Earth.	L.A.S.	Leakage ammeter shunt (Aycliffe only)
Rh.	Rheostat.		
V.M.P.S.	Volt-meter plug-socket.	Me.S.	Machine - feeder shunt.
B.V.	Bus-bar volts.	Sh.T.	Shunt trip-coil.
M.V.	Machine volts.	Rs.	Resetting device for machine. C.B.
F.R.S.	Field-splitting & reversing-switch. 100a	B.A.	Battery for alarm-bell.
A.S.	Ammeter-shunt.		
M.S.	Meter-shunt, 1200 a.	T.B.	Tripping-battery (to give duplicate supply).
D.R.	Differential relay.		
R.C.S.	Reverse-current coil.		
Mg.B.	Magnetic blow-out.	B.Ch.S.	Battery change-over switch.
O.T.C.	Over-load trip-coil.		
R.V.	Recording volt-meter. 0-20 volts.	T.C.	Trip-coil (30 volts).
		T.C.S.	Trip-coil switch.
L.A.	Leakage ammeter (at Aycliffe only 0-5 : 0-50 a.).	A.B.S.	Alarm-bell switch.
		F.T.L.	Fuse time-limit.
C.B.	Circuit-breaker. Machine 1200 a.	A.P.	Ammeter plug.
		O.R.	Overload relay.
T.C.S.	Trip-coil switch.	S.C.R.	Split conductor relay (Aycliffe only).
S.E.	Starting & equaliser switch. 500 a.	S.P.C.T.	Split-cond. current-protection transfr. (Aycliffe only).
S.S.	Starting and series switch. 500 a.	S.C.T.	Secondaries of protection transf'mer.
C.Bx.	Cable-box.		
W.T.T.	Watt-meter testing terminals.	O.C.T.	Overload current transformer.
R.C.	Reactance coil (shown by a ×, ½ v. Tappings only).	W.C.T.	Watt-meter current transformer.

NOTE.—Of the two E.H.T. feeders at Aycliffe and Erimus only the connections for one are shown, both being alike.

cent. momentarily. The machines were subjected to a high potential test of 5000 volts for 5 minutes. On account of the high voltage on the commutator, these machines were specially designed to avoid damage due to flash-over, occasioned by short-circuits on the system. The operating parts of the brush-gear were entirely enclosed, the distance between brush-arms was made as great as possible, and the commutator was completely screened by arc-proof insulating material from the armature and frame of the machine.

Tests were carried out to determine what load could be suddenly thrown on and off these sets without flashing. Five times full load was thrown on and automatically tripped off with a breaker seven times, and three times out of the seven the machines stood this severe test without flashing. Fig. 46, page 524, shows an oscillograph which was taken during one of the tests when the rotaries did not flash over.

The British Thomson-Houston Company, Limited, of Rugby, are at present installing at Erimus another set, but of 1200 kw. capacity, consisting of two 600-kw. rotary converters coupled in series to form one unit.

Power to these sub-stations is obtained from the N.E.S. Co., the voltage of supply being 20,000 volts three-phase for Aycliffe sub-station, and 11,000 volts three-phase for Erimus substation, the periodicity being 40 cycles. At the sub-stations this power is converted by means of six-phase rotary converters to 1500 volts D.C., this being the supply voltage to the overhead line.

In each of the above sub-stations the E.H.T. switch-gear is of the ironclad compound filled type, the ironclad gear being fitted in a special chamber on the switchboard gallery, with the control panels and instruments mounted immediately in front of same. A special feature of the transmission scheme is the high-voltage D.C. gear. This switch-gear (see Figs. 40 to 44, Plate XLVI.) has been designed somewhat on the lines of that usually adopted for high-tension A.C. boards; that is to say, the apparatus is of the remote-controlled type and is mounted in a cell structure built up of brick walls with moulded stone division slabs, each equipment being thus entirely separated from its neighbour.

The individual cells are built up on the cubicle system; that is to say, special compartments are provided for :—

1. Busbars and isolating switches (top cubicle).
2. Circuit-breakers (intermediate cubicle).
3. The bottom cubicle contains the operating mechanism for the isolating switches and circuit-breakers, also the connecting cables passing up to the circuit-breaker units.

From this it will be seen that no high-tension gear is accessible below the circuit-breaker cubicle. Further, when it is desired to work on the circuit-breakers these can be entirely disconnected from the busbars by means of busbar isolating switches. The circuit-breakers and busbar isolating switches are mounted on polished white marble panels built into the cell structure, suitable angle-iron supports being provided for bolting into the brick division walls.

The busbar isolating switches are of the high-tension rotary type; that is to say, the contact units are mounted on porcelain insulators carried on moulded stone slabs, forming part of the cell structure. The contact blades are fixed on porcelain insulators of the sleeve type, carried on a rotating shaft fixed to the cell structure by means of stout wrought-iron brackets.

The circuit-breakers included in this scheme are specially designed for high voltage work, the break being exceedingly large and quick. The breakers are of the brush contact type with auxiliary copper sparking-tips, and special carbon blocks to take the final break. These blocks are designed with an ample margin of contact area, and in addition are fitted with magnetic ears in order to take care of the breaking of the arc. On service this device has been found to give exceedingly good results. The feeder circuit-breakers are of the plain overload type, and are designed to give a very heavy setting in order to take care of the momentary overloads experienced in a traction system of this description. The machine circuit-breakers are of the overload and reverse-current type. In conjunction with the reverse current a special single-pole relay of the differential type is provided, so that in the event of the rotary converter coming up of the wrong polarity, it is impossible to close the circuit-breaker on to the busbars. This relay is coupled up across the main contacts of the circuit-breaker and operates a shunt trip-coil fixed to the circuit-breaker release mechanism. This shunt trip-coil is also arranged for operating from the over speed device on the rotary converter sets.

For the metering of the power in the sub-stations, integrating wattmeters are fitted on the E.H.T. rotary equipments, and on the D.C. side two-wire integrating watt-hour meters are fitted on the instrument panel. Three of these meters are furnished for check purposes and are operated from the same shunt, the shunt being fitted in the negative busbar between the machines and the feeders.

The control panels are of cast iron and form the front section of the bottom cubicles. On these panels are mounted the operating handles for controlling the circuit-breakers and busbar isolating switches. The arrangement of these panels is very clearly illustrated in Figs. 41 to 44, from which it will be seen that practically no exposed part projects beyond the surface of the panel, other than the operating handles. The instruments are of the vertical edgewise type and are arranged for mounting behind the panel, a suitable slot with glass front being provided in the panel for these meters. The instruments themselves are carried on porcelain insulators fitted to the back of the panel casting.

The starting gear on the three 800-kw. rotary sets—that is to say, two at Aycliffe sub-station and one at Erimus sub-station—is of the controller type, the machines being arranged for tap-starting. These controllers are mounted at the end of the machine frames and are fixed directly to the main floor of the sub-station the connections being taken straight down and carried on the basement floor. With regard to the larger sets furnished in Erimus sub-station, these rotaries are of the self-synchronising type, the starting gear consisting of oil switches mounted in the transformer chamber and operated direct from the switchboard gallery, two oil switches being furnished for each rotary converter, one for the main rotary connections, and the other for the starting motor. The operating mechanism for these oil switches is of the signal lever type, the operating shafts being carried on the underside of the basement floor. In conjunction with this latter starting gear an operating handle is provided for controlling the series switch on the D.C. side of the rotary converter; this handle is mounted alongside the operating handles of the starting switches, and a system of interlocks is furnished for these three units, arranged so that:—

1. Before closing the starting motor switch the other two switches must be "off."
2. Before closing the main oil switch the starting switch must have been closed.
3. The closing of the series switch automatically opens the starting switch.

In conjunction with this starting gear an instrument panel is fixed alongside the operating handles. This panel contains an A.C. voltmeter to indicate that the rotary is in synchronism before closing the main starting switch. A D.C. voltmeter is also fitted to indicate the voltage of each rotary before closing the series switch.

In connection with the 800-kw. rotary sets, field splitting switches are provided of the remote-controlled type arranged for operating direct from the switchboard gallery. These switches are mounted in the basement floor in the same structure as the main series switch supplied in connection with each rotary. This structure consists of marble panels completely covered in with expanded-metal screen-work. The operating handles for controlling these switches are mounted on cast-iron pedestals fixed immediately in front of the D.C. control board.

The rheostats for the rotaries are mounted in the basement floor, and are controlled by operating hand-wheels fixed on the machine-control panels, bevel gearing being provided for coupling up the control hand-wheel on the switchboard gallery to the rheostats in the basement.

For the lighting of each sub-station, and also for controlling the portable air-compressor, two 20-kv.a. three-phase transformers have been supplied. These transformers are coupled up in parallel on the E.H.T. side with the main step-down transformers for the rotaries. On the L.T. side, however, a change-over switch is provided, so that either of the two auxiliary transformers can be coupled up to the lighting circuit at will, 110 volts being the lighting voltage. The lighting switchboard is of the standard flat-back type, consisting of black enamelled slate carried on a pipe framework structure arranged for bolting to the sub-station wall, and is fixed on the switchboard gallery at right angles to the main D.C. control-board. As already mentioned, in addition to supplying the lighting, this board also supplies power to the portable air-compressor set and a spare circuit is provided for the installation of ventilating fans at some later date.

In concluding our notice of the Shildon-Newport electrification, which marks an extremely important innovation in the handling of freight in this country, it may be of interest if we point out that the freight of our railways, whether measured by volume or value, constitutes by far the larger proportion of the total traffic. In the case of the main lines of the country, the statistics for 1913 show that the total traffic receipts were made up as follow:—

	£	Per Cent.
Goods	66,639,709	= 54
Mails, parcels, and other merchandise sent by passenger train ...	9,836,414	= 8
Passengers	47,141,412	= 38
Total	123,617,535	= 100

In the case of railways serving the great industrial districts, the preponderance of goods traffic, as would naturally be expected, is very much more pronounced. The North-Eastern Railway Company in 1913 employed

NORTH-EASTERN RAILWAY ELECTRIFICATION.

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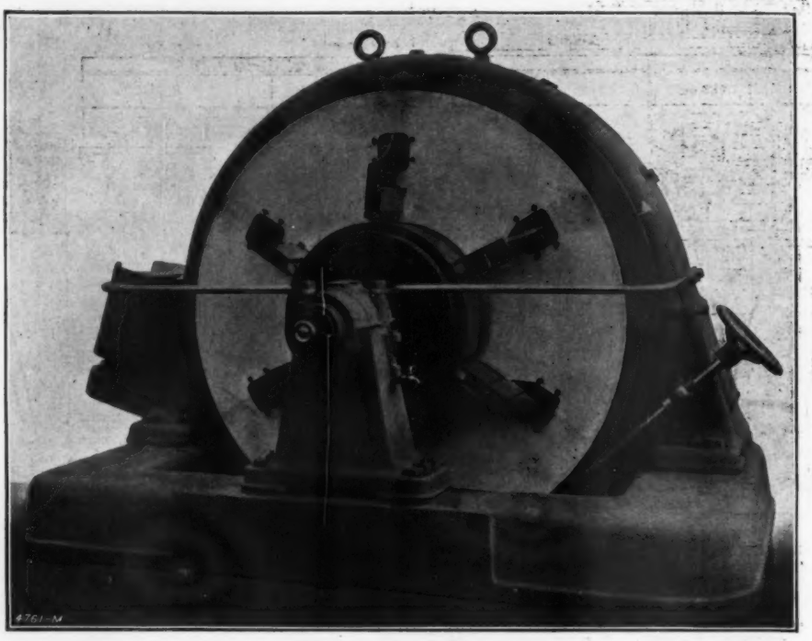


FIG. 45. ROTARY CONVERTER.

FIG. 46. OSCILLOGRAPH TAKEN DURING TEST.

for their goods traffic 117,959 wagons, while for their passenger traffic only 4879 coaches were used. Their total traffic receipts for the year were made up as follow:—

	£	Per Cent.
Goods	7,374,699	= 66
Mails, parcels, and other merchandise sent by passenger train ...	683,870	= 6
Passengers	3,134,736	= 28
Total	11,193,305	= 100

It would be of very great interest to know what proportion of the total capital expenditure of the railways has been incurred for passenger as compared with goods traffic. Probably an accurate estimate would be impossible, but there is every reason to believe that Senator Hill was correct in his assertion, that if allowed to build a railway for freight service only, he could fix freight rates at a price far below what would be possible on any artificial waterway. In any case, the cheap and efficient handling of the goods traffic of the country is a matter of national importance, and the working of the Shildon-Newport installation will be followed with the greatest interest.

For freight service the electric locomotive has some peculiar advantages. Having no boiler, there is little restriction on its size and power, and, owing to its simplicity of structure, it can spend a much larger proportion of its life on active service than a steam locomotive.

The present enterprise was, of course, greatly facilitated by the existence of the remarkable system of power distribution which, through a fortunate inadvertence, our legislators failed to stifle in its infancy. The mains constituting the distributing system of the North-East Coast group of electric power companies cover the whole of the industrial areas of Northumberland and Durham, to which must be added the Cleveland corner of Yorkshire. The smaller power stations are in many cases operated with waste heat from collieries, coke

ovens and steel plants, whilst the main power stations, with their steam turbines, have been operated with astounding efficiency. In fact, for certain purposes power can be sold more cheaply than by most hydro-electric stations.

INDUSTRIAL NOTES.

The Executive Council of the South Wales Miners' Federation met at Cardiff on Saturday last, May 27. The resignation of Lord Muir Mackenzie as independent chairman of the South Wales Coal Conciliation Board was accepted. The Board met at Cardiff on Monday last, the meeting having been convened at the instance of the Board of Trade; Sir George Askwith was at Cardiff to act as conciliator should his services be called upon. The position in regard to wages was considered, the men demanding a 15 per cent. advance, whilst the coalowners have put forward a 7½ per cent. reduction. No settlement having been reached at the meeting, it was decided that Sir George Askwith should receive a deputation from the men, in London, on Tuesday. We understand that no agreement was reached at Tuesday's meeting, and a further interview between Sir George Askwith and the officials of the South Wales Miners' Federation took place on Wednesday, when after hearing the men's case, Sir George stated that he would consult the coal-owners and communicate further with the men's representatives.

On Saturday last the Card-Room Amalgamation refused the employers' offer of a 5 per cent. increase in wages, and maintained their demand for a 10 per cent. increase, on the basis of the increased cost of commodities and of the profitable state of the trade. The employers offered the 5 per cent. increase provided an agreement were signed for the regulation of wages for a period of ten years. The operatives urged that the present time was inopportune for framing agreements, and promised to consider favourably the matter six months after the end of the war. At the close of Saturday's meeting the Card-Room and the Spinners' Amalgamations decided that the strike notices which had been handed in, and had been suspended during the negotiations, should again become operative. If no agreement is arrived at, these notices are to take effect from to-morrow, June 3. The dispute involves about 300,000 operatives. At the time of writing, meetings are being held between employers and operatives with a view to the settlement of the dispute.

Mr. Lloyd George, who was accompanied by Mr. Arthur Henderson, M.P., President of the Board of Education, and by the members of the National Labour Advisory Committee on War Output, met on Monday last the representatives of the principal trade unions at the Ministry of Munitions, Hotel Metropole.

Amongst the chief societies represented were the Amalgamated Society of Engineers, the Boilermakers' Society, the Steam-Engine Makers' Association, the National Transport Workers' Federation, the National Union of Railwaymen, the Shipwrights and Ship Constructors' Association, the Associated Iron and Steel Workers, the British Steel-Smelters' Society, the Amalgamated Society of Carpenters and Joiners, the General Union of Carpenters and Joiners, the National Furnishing Trades' Association, the Blacksmiths' Society, and the National Braasworkers' Association.

Some of the prominent leaders taking part were Mr. Harry Gosling (President of the Trade Union Congress), Mr. J. E. Williams (National Union of Railwaymen), Mr. John Hill (Boilermakers' Society), Mr. Robert Williams (National Transport Workers' Federation), and Mr. W. Mosses (Secretary of the National Labour Advisory Committee).

The object of the meeting was to appeal for the postponement of the Whitsuntide holidays in order to prevent any diminution in the output of guns, munitions and other necessary military supplies. It is understood that the representatives present unanimously agreed that the holidays in question be postponed for two months, *i.e.*, until after the end of July.

The Miners' Federation of Great Britain, which has had the question of the curtailment of holidays under consideration for some time, at the request of the Home Office, was not present.

In the House of Commons on Wednesday last, the Prime Minister, Mr. Asquith, stated that Parliament proposed by Proclamation to postpone the Whit-Monday holiday until Tuesday, August 8, and he understood that the bankers were agreeable to this arrangement. It was fully recognised, he added, that both in munition works and in other trades it would be necessary that individual employees who were feeling the effects of overstrain should in suitable cases be granted leave of absence; but it was in the highest degree undesirable that during the period referred to any holidays should be granted which involved suspension of work in the establishment.

On Wednesday also, Mr. A. Henderson addressed a meeting at Manchester of employers and operatives employed on munition work, when he said that the postponement of the Whitsuntide holiday was necessary in order to maintain the required output of munitions. The meeting passed a resolution agreeing with the scheme.

At a meeting of the National Advisory Committee the question of the Government control of food prices was fully considered, and it was decided to acquiesce in an application from the annual meeting of the Federation of Engineering and Shipbuilding Trades, that the Executive Council of that body, together with representatives from its various District Committees, should, with the Parliamentary Committee of the Trade Union Congress, wait upon the Minister of Munitions and the President of the Board of Trade with a view to discuss with these Ministers the apparent embargo which has been placed upon any further general increase of wages, together with the steady and continuous increase in the cost of living. A considerable amount of information has been obtained respecting the various increases of wages which have been granted in different trades to the workmen concerned in the manufacture of munitions, together with much statistical information with regard to the increase in the cost of living in these districts; this information will be available for the proposed conference which it is expected will be held shortly.

Many will make fortunes in the manufacture and sale of war munitions, says *Machinery*, New York, in a short paragraph entitled "Dangerous War Business," and many will lose money as a result of undertaking to manufacture products with which they are unfamiliar or owing to conditions over which they have no control. The following extract from a circular letter which was recently sent to the creditors of a company reveals a situation that probably has many parallels:—

"We regret to be obliged to ask our creditors for a general extension of time for the payment of our accounts.

"In explanation we would say that in September, 1915, we entered into a contract for machining 250,000 shrapnel shells, to be done at the rate of 1000 to 1200 per day, beginning on November 1, 1915. We immediately changed our machines, so as to enable us to do the machining, but we were at first delayed by the failure of the owners of the work to furnish correct gauges and standards; we were further delayed later by changes made in the specifications, and by the failure of the inspectors of the work to arrive and make examinations of what had been already done until January, 1916. A new change was agreed upon in the specifications, not contemplated at the time of the making of the original contract, which necessitated the purchase of six grinding machines. Owing to the present conditions and to congestion of orders in the machine-making factories, it was found impossible to obtain these machines until late in the summer. We had therefore to make arrangements with the owners of the work to supply us with the necessary grinding machines; they have agreed to make and deliver these.

"Meanwhile, with no income, we have exhausted our resources and are at the present time shut down. We are assured by experts that we have a good contract and one which, if carried to completion, would not only pay all our indebtedness but leave a substantial profit for our stockholders. The quality of our product thus far has shown that we are able to do the work satisfactorily and below the figures we estimated when the contract was entered into. All that we need is the time to swing ourselves."

With reference to the American Tavenner Bill, the same journal, *Machinery*, says that scientific management is a term used to designate the application of scientific methods, or the application of human efficiency to benefit the employee by lightening labour, augmenting output and increasing earnings; to benefit also the employer by augmenting output and thus decreasing the cost of production. In view of the mutual advantages that accrue from improved methods of manufacture—the better utilisation of human effort and increased productiveness of investment in machinery and plant—the objections on the part of labour leaders, legislators and others, to the scientific investigation of manufacturing methods seem absurd. To forbid the Government by law to purchase materials made in an establishment where scientific management is followed, would compel the Government to use materials made in the least progressive and efficient plants, often, if not always, at higher costs. It would tend to discourage, instead of encouraging, American manufacturers in preparing to meet the competition of other countries.

A similar note is struck in a speech by Mr. James A. Emery, delivered before the National Metal Trades Association, New York, reported in the *Iron Age*. Mr. Emery said:—". . . Our greatest industrial need in this hour is skill and efficiency. We must make the best operatives, while making the best commodities. It is every employer's duty to encourage the training of skilled industrial soldiers to meet the assault of international competition; it is every worker's duty to become an efficient member of the army of industrial self-defence. To attain this end, we must have free play for capital and labour, unhampered by unintelligent and uneconomic legislation, which is discouraging and cramping to private initiative; we must also have liberty of development and opportunity for every workman, so that the latter can make the best of that which is in himself, to his benefit and to that of society . . . . Legislation as a social cure-all for the inequalities of life, as a pleasing way of distributing the fruits of success to the unsuccessful, as a popular method of conducting social experiments at the expense of the frugal, the efficient and the well-to-do, has made persuasive appeals. The chief subject of attack is the business man, and the business man cannot succeed without lifting others up; he makes two jobs grow where one grew before; and he has been, broadly speaking, the one unorganised element in a maelstrom of systematic determined effort to control his action, restrict his operations, tax his earnings, discourage the reinvestment of his profit—if any he makes—deprive him of essential legal protection from powerful industrial organisations, and subvert and re-shape the vital character of his government. The employer, carrying the chief financial burden of government and all the responsibility of supervising and directing commerce and industry, is the victim at every turn of organised effort. Timid public men, overawed by organisation, have become, by the very circumstances of the hour, the persecutors of business, because it is unorganised. . . . The American employer can neither meet the abuses of organisation except by counter organisation, nor ascertain or systematically arrange the complex facts of our industrial life without organisation. Without joining with his fellows, he can neither acquire nor express an articulate collective judgment that can rightly impress the makers and administrators of law. The lesson of the hour is organisation for the American employer, that he may with his fellows stand shoulder to shoulder in the defence of his rights and the study and development of sound policies of business statesmanship to meet the serious circumstances of the day.

THE GREAT LAKES.—The quantity of iron ore at Lake Erie Docks at the close of April was 3,311,000 tons. This was less than at the corresponding date in any year since 1907, the total for April, 1915, having been 5,900,000 tons. Shipments from Lake Superior ranges in April were 1,658,411 tons, as compared with 503,832 tons in April, 1915, showing an increase of 1,154,579 tons. This great increase augurs well for 1916, breaking all records. While the Duluth and Superior percentages of the total were about the same as last year, the Escanaba contribution was much larger in consequence of an earlier breaking up of the ice.

SUBMARINE TELEGRAPHY.—The revenue of the Eastern Telegraph Company for 1915 amounted to 2,104,432*l.*, reduced by 655,889*l.* by ordinary working expenses and 202,609*l.* by maintenance of cables, differences in exchange, &c., leaving a balance of 1,245,934*l.*, to which should be added 32,742*l.* brought forward from 1914, making available 1,278,675*l.* The directors placed 460,000*l.* to the general reserve and 15,000*l.* to the company's other numerous reserves. The dividend for 1915 was increased from 7 per cent. to 8 per cent., and 26,638*l.* was finally carried forward. The general reserve fund has been charged with 204,880*l.* in respect of a new Aden and Colombo cable and other special expenditure, and with 125,000*l.* as a further provision for investment fluctuations. The net addition to the general reserve fund for 1915 was 130,120*l.* The value of the cable used for maintenance purposes last year was 34,414*l.*, and 15,984*l.* was charged for depreciation of spare cable. The value of the spare cable and other stores held by the company at the close of last year was estimated at 373,892*l.* Cable, land lines, stations, ships, and investments in other companies stood in the books at the close of 1915 at 8,052,974*l.*

NORTHERN AUSTRALIA.—By the Northern Territory Acceptance Act the Northern Territory of South Australia was transferred to the Australian Commonwealth, and it is now administered by the Department of External Affairs. By the Acceptance Act the Commonwealth undertook to construct a transcontinental railway from Pine Creek southwards to connect with the Port Augusta line, and also to purchase from South Australia a railway line from Port Augusta to Oodnadatta. The Pine Creek line is in course of development, and it is expected that it will reach the Katherine, 70 miles from Pine Creek, before the close of this year. The capital of the Northern Territory, wich was originally called Palmerston, has been renamed Darwin. The town is situated on Port Darwin. The harbour equals in size any in the world, and it is capable of accommodating vessels of 10,000 tons burthen. Some wide streets have been well laid out, and there is an esplanade bordering the town for nearly 2 miles. At present the most important occupation in the Northern Territory is pastoral industry. Gold, tin, copper, silver, lead, wolfram, &c., are being mined, and geologists are of opinion that the natural resources of the territory are great; at present, however, little actual mining has been done.

THE LAWS OF SKIN FRICTION.

*The Laws of Skin Friction of a Fluid in Stream Line and in Turbulent Motion along a Solid of Great Length.**

By CHARLES H. LEES, D.Sc., F.R.S.

INTRODUCTION.

1. THE problem of the resistance experienced by a ship or other long pointed body in motion parallel to its length on the surface of water is a difficult and complicated one, largely owing to the fact that the resistance is due to three causes:—First, the frictional resistance of the water moving past the surface of the body and amounting at speeds of 5 or 6 knots to 80 or 90 per cent., and at speeds of 20 knots to 50 per cent. of the total resistance. Second, the resistance due to the formation of eddies alongside and in the wake, which in ships of good form Mr. Wm. Froude estimated at about 8 per cent. of the total resistance. Third, the resistance due to wave-making on the surface of the water, which at speeds of 6 to 8 knots may be only a few per cent., but at 20 knots becomes 40 per cent. of the total.

2. The frictional resistance, forming as it does more than half the total, has been the subject of careful measurement by Mr. Froude,† in this country, by Tideman,‡ in Holland, and by Geber,§ in Germany. Each made use of long flat boards towed under water with their breadths vertical and their top edges an inch or two below the surface of the water to diminish surface waves to a minimum. Mr. Froude's boards were $\frac{1}{16}$ in. thick, 19 in. broad, and up to 50 ft. in length, and were towed at speeds between 100 and 800 ft. per minute. Each arrives at the conclusion that the skin friction F of such boards is expressed by:

$$F = f A V^n \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where f is the frictional constant depending on the nature of the wetted surface of the solid, A is the area and V the velocity of that surface; n is a constant which depends on the nature of the surface of the solid, and for the freshly painted hull of a ship is generally taken as 1.83.

According to Froude the frictional resistance is nearly independent of the form of the section of the body moved through the water so long as the wetted perimeter of the section remains the same.

3. The risk involved in extending this expression from flat boards 50 ft. by 2 ft. moving with speeds not exceeding 800 ft. per minute to ships 800 ft. long, 90 ft. beam, and speeds of 26 knots, *i.e.*, 2600 ft. per minute, has been felt by all,‖ but the fact that no serious discrepancies have been found shows that it is not far from the truth. The subject will be put on a much firmer basis when data for bodies of intermediate size have been secured, by measurements made on submarines 100 ft. to 200 ft. long towed under water.

In view of the limited range of the experiments on which the formula for the frictional resistance is based, it seems desirable to consider the evidence provided in support of, or in opposition to, the formula by experiments in other directions. As several new results have been reached during the past four or five years, it seems advisable to put them before naval architects for their consideration.

ON THE FRICTIONAL RESISTANCE TO THE FLOW OF FLUIDS THROUGH PIPES.

4. When a fluid of density ρ flows through a length l of a smooth pipe of diameter d with a mean speed over the section of the tube of v, not sufficiently large to cause the motion of the fluid to deviate from stream-line motion, the frictional resistance F to its motion is given according to Stokes by:

$$F = 8 \pi \eta l v \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where η is the viscosity of the fluid. When the speed of the fluid is increased above a certain value, called by Reynolds the "critical velocity" for that fluid and pipe, the frictional resistance increases faster than the first power of the velocity, and at high speeds becomes nearly proportional to the square of the mean velocity. We propose to call the motion under the first law "stream-line motion," and when deviation from this law commences to call the motion "eddying or turbulent motion."

5. The experimental results obtained by Stanton and Pannell¶ at the National Physical Laboratory in the turbulent flow of water and other fluids through smooth brass pipes of diameters 0.3 to 12 cm., at speeds from 5 to 5000 cm. per second, and those obtained by Saph and Schoder** at Cornell University on water in pipes from 0.3 to 5 cm. diameter, have been shown recently to lead to the following simple formula for the total frictional resistance F of a smooth pipe of length l, diameter d, through which a fluid of kinematical viscosity γ is flowing with mean speed v:—

$$F = \pi \rho l d v^2 \left\{ a + b \left(\frac{\gamma}{d v} \right)^n \right\} = A \rho v^2 \left\{ a + b \left(\frac{\gamma}{d v} \right)^n \right\} \dagger\dagger \quad (3)$$

where A is the area of the surface of the length of pipe, $a = 0.0009$, $b = 0.0765$, $n = 0.35$, whatever be the fluid or the system of units used.

From the form of this expression it will be seen that for all mean velocities above the critical, for which:—

$$\frac{d v}{\gamma} = 3000 \text{ about},$$

the resistance over small ranges of velocity will vary approximately as a power of the velocity between 1.65 and 2.0, and that, as the diameter of the pipe increases, or the speed increases, or the kinematical viscosity decreases, the resistance will vary more nearly as the square of the velocity.

The single power of the velocity which gives the best approximation in the neighbourhood of a particular value of $\frac{d v}{\gamma}$ is:—

$$n_1 = 2 \frac{1 + \left(1 - \frac{n}{2}\right) \frac{b}{a} \left(\frac{\gamma}{d v} \right)^n}{1 + \frac{b}{a} \left(\frac{\gamma}{d v} \right)^n} \quad . \quad . \quad (4)$$

ON THE RESISTANCE TO THE MOTION OF LONG BODIES TOWED THROUGH WIDE PIPES.

6. The pipe problem which most nearly approaches that involved in the motion of a ship is, however, not that of flow of a liquid through the pipe, but that of the motion of a long solid towed through a pipe filled with liquid. If we suppose the wetted portion of the body of a ship of beam B and moulded draught δ, moving along a wide canal, to be duplicated, the copy turned upside down and placed on the original, so that the water-lines coincide, we have a body (Fig. 1) which when towed, with the speed of the ship, through a pipe of breadth equal

Fig. 1.

Fig. 2.

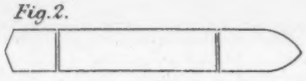


Fig. 3.

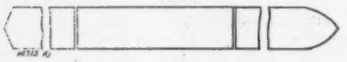
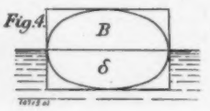


Fig. 4.



to that of the canal, and of height twice the depth of the canal, would meet with a frictional resistance double that of the ship. If we now cut off the bow and stern (Fig. 2), and replace them by long lengths of parallel mid-body, to the ends of which the bow and stern are then attached, we arrive at a very long body (Fig. 3) towed through a long pipe filled with liquid. We propose to summarise some recent extensions of our knowledge of the resistances encountered by the centre lengths of such bodies of approximately ship sections when towed slowly through a wide pipe, so that the motion of the liquid is strictly stream-line motion.*

The sections of greatest interest are those with breadth B and height 2 δ, which lie between the rectangle and the inscribed ellipse, whose sectional coefficient will be 0.785 (Fig. 4). The submarine falls into the latter class with $B = 2\delta$.

7. When a very long body, whose cross-section is an ellipse of semi-axes a_1 and b_1, is towed with speed v through the centre of a wide tube whose section is a confocal ellipse of semi-axes a_2 and b_2, the frictional resistance F to the motion of a length l near its centre is given by:—

$$F = \frac{2 \pi \eta l v}{\log_\epsilon \frac{a_2 + b_2}{a_1 + b_1}} \dagger \quad . \quad . \quad . \quad (5)$$

Where η is the viscosity of the fluid filling the tube, the logarithm is to the base ϵ and the fluid is in stream-line motion.

When the outer tube is very wide, a_2 and b_2 become almost equal, and the tube may be considered one of circular section of diameter $= a_2 + b_2$. Under these circumstances the formula allows us readily to compare the resistance of bodies of different elliptical, circular, or flat sections towed through the same tube or canal. Thus keeping $a_2 + b_2$ of the outer tube the same, and the speed of the body in the tube the same, we notice that so long as $a_1 + b_1$ is kept the same the resistance will be the same. Hence bodies of elliptic sections moving with the same speed through fluids filling wide tubes experience the same resistance if the sums of the semi-axes of the sections are kept the same. Since it will be convenient to refer all sections to the circular section of the same resistance, we may state the law thus:—The diameter of the circular section of equal resistance to any elliptic section is equal to the sum of the semi-axes of the elliptic section. This holds for sections varying from that of a thin strip to that of a circular cylinder. In the case of a long, thin, flat strip it will be noticed that the diameter of the circular cylinder of the same resistance will be half the width of the strip.

8. When the section of the body towed through the tube differs from an ellipse, the expression for the resistance is not so simple. When the section is rectangular, it has been shown recently* that for rectangles whose half sides are respectively a and b where:—

$$a = 2 \cdot E_1(\alpha) - 2 \cdot \cos^2 \alpha \, F_1(\alpha)$$

and

$$b = 2 \cdot E_1\left(\tfrac{1}{2}\pi - \alpha\right) - 2 \cdot \sin^2 \alpha \, F_1\left(\tfrac{1}{2}\pi - \alpha\right)$$

E_1 and F_1 being the complete elliptic integrals of the second and first kind respectively, and α an angle between O and $\frac{1}{2}\pi$, the rod of circular section, which has the same resistance when towed at the same speed, has a diameter = 2.0.

From this it may be shown that the diameter d of a body of circular section, which will have the same resistance as a body of rectangular section, whose long half side is a, and short half side b, is given by:—

$$d = (a + b)\left(1 + \frac{1}{4}\sqrt{\frac{b}{a+b}}\right) \quad . \quad . \quad (6)$$

with an error not exceeding 3 per cent.

To facilitate the use of the equivalent circular section, the following table has been calculated for the rectangular sections by the accurate expression involving elliptic integrals, and for the elliptic sections by the formula (5), already given.

Table of Equivalent Moulded Breadths B_0 of Long Parallel Mid-body of Semicircular Section, having the same resistance for Stream-Line Motions as an equally Long Parallel Mid-body of Moulded Breadth B = 1, Moulded Draught δ and either Rectangular or Elliptic Section, and Sectional Coefficients 1 or 0.785 respectively.

δ	Equivalent Breadths B_0	
	For sec. coef. 1.	For sec. coef. 0.785
0.500	1.18	1.00
0.464	1.14	0.964
0.429	1.10	0.929
0.397	1.06	0.897
0.368	1.02	0.868
0.341	0.989	0.841
0.314	0.958	0.814
0.291	0.928	0.791
0.269	0.899	0.769
0.249	0.873	0.749
0.229	0.848	0.729
0.152	0.745	0.652
0.095	0.662	0.595
0.057	0.604	0.557
0.030	0.562	0.530
0.013	0.530	0.513
0.003	0.508	0.503
0.000	0.500	0.500

With the help of this table, or Fig. 5, or the formulæ (5) and (6) previously given, any problem with regard to the frictional resistance of a very long body of rectangular or elliptic section towed along a wide tube filled with liquid can be reduced to the simpler problem of a long circular cylinder towed along the same wide tube, so long as the liquid moving past the body is in stream-line motion.

9. When the speed of the long body is increased, eddy currents begin to be formed in the liquid, the motion ceases to be stream-line motion in the strict sense, and becomes eddying or turbulent motion. For the resistance brought about by such motion we have no satisfactory theory, and are compelled to fall back on experiment and on empirical formulæ for the range outside that of direct observation.

10. The principle of physical dimensions as applied by Lord Rayleigh† to the case of the turbulent flow of fluid through a smooth pipe of circular section is equally applicable to the motion parallel to its axis through a fluid of a very long body of circular section. It is found that the resistance per unit area of wetted surface must be proportional to:—

$$\rho v^2 f\left(\frac{\gamma}{d v}\right),$$

where:—

$$f\left(\frac{\gamma}{d v}\right)$$

is some unknown function. This makes the skin friction on a length l of the long body proportional to:—

$$\rho v^2 d l f\left(\frac{\gamma}{d v}\right).$$

If, then, experiment shows us that the skin resistance is proportional to the nth power of the velocity, the function must be:—

$$\left(\frac{\gamma}{d v}\right)^{2-n}$$

and the force on a length l of the body will be proportional to:—

$$\rho v^2 d l \left(\frac{\gamma}{d v}\right)^{2-n}.$$

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* Paper read before the Institution of Naval Architects, April 12, 1916.

† W. Froude, "Reports of the British Association," page 118 (1872), page 249 (1874).

‡ Tideman, Results quoted by Taylor, "Speed and Power of Ships," Table VI.

§ Geber, "Schiffbau," IX. Jahr. 6 and 7.

‖ Taylor, in his "Speed and Power of Ships," page 61, for example, says it is "speculative to some extent."

¶ Stanton and Pannell, Phil. Trans. Royal Society, A, vol. cxiv., page 199, 1914.

** Saph and Schoder, American Society of Civil Engineers' Proceedings, vol. li., page 253, 1903.

†† Lees, Roy. Soc. Proc. A., vol. xci., page 49, 1914. Recently Lander has shown that with $a = 0.002$, $b = 0.141$, $n = 0.44$, the formula covers his measurements on the flow of water and steam through small rough wrought-iron pipes. (Roy. Soc. Proc. A., vol. xcii., 1916.)

* See Lees, Roy. Soc. Proc. A., vol. xcii., page 144, 1915.

† See Lees, *loc. cit.*, page 149.

* See Lees, *loc. cit.*, page 153.

† Rayleigh, Phil. Mag., 34, page 59 (1892), Aeronautics Report, 1911–12, page 97.

Lord Rayleigh* has pointed this out in connection with Zahm's† results for the frictional forces on flat boards along which a current of air is moving, and the same remark is applicable to Froude's results for the frictional resistance to flat boards towed through water. Taking $n = 1.83$ for boards in water, we have the resistance of a length l proportional to $\rho^{0.17} l d^{0.83} v^{1.83}$.

We do not appear to have sufficient data as to the resistance of boards of different breadths to enable us to decide between the $d^{0.83}$ of this expression and the $d^{1.0}$ of the formula usually taken, but there seems no doubt that if the frictional resistance of a very long body of circular section is proportional to a single power of the velocity less than 2, the diameter of the body should come in to a power less than 1 by the same amount.

11. The frictional resistance of the walls of a pipe was formerly taken proportional to $v^{1.7}$, but, as measurements at higher speeds became available, it was found necessary to take a higher power as the speed increased. Up to the present nothing simpler that the double power formula (3):

$$F = \rho . l \pi d . v^2 \left\{ a + b \left(\frac{\nu}{d v} \right)^n \right\}$$

already given, seems adequate to cover the whole of the data available.

It seems highly probable that, as data for the frictional resistance of very long bodies moving through water accumulate, a formula of this type will become necessary, for there is nothing fundamentally different in the motion of the liquid past the wall of a pipe and in its motion past the surface of a very long body towed through it.

12. To show the close connection between the two cases, we may take the pipe formula with its constants fixed by modern pipe experiments and assume that it is applicable to very long bodies of circular section towed through liquids. The diameter of the pipe becomes the diameter of the body, and we may in the first instance take the mean velocity through the pipe as the analogue of the velocity of the body. It will then be possible to calculate the resistance of a length l of the body for a given velocity. As, however, there are no measurements of the frictional resistances of long bodies of circular section available with which to compare the calculated results, we may calculate the frictional resistance of a circular cylinder which in stream-line motion would have the same frictional resistance as the flat varnished boards used by Froude, and compare the results of the calculation with those obtained by Froude‡ from his experiments.

Froude's boards were $\frac{1}{4}$ in. thick, 19 in. broad, and of various lengths up to 50 ft. The circular cylinder, which would have the same resistance in stream-line motion, has a diameter 9.6 in. = 24.4 cm., while the cylinder of equal resistance in eddying motion, according to the generally accepted theory, would have the same surface as the board, *i.e.*, a diameter of 12.23 in. = 31.1 cm.

Taking the last alternative and calculating by means of the pipe formula :—

$$F = \pi l d v^2 \left\{ 0.00090 + 0.0765 \left(\frac{\nu}{d v} \right)^{0.35} \right\}$$

which for water at 15 deg. Cent. reduces to :—

$$F = l d v^2 \left\{ 0.00283 + 0.0502 \left(\frac{1}{d v} \right)^{0.35} \right\}$$

the frictional resistance of a length of 1 ft. = 30.5 cm. we get :—

$$F = v^2 \left\{ 2.68 + 14.4 \left(\frac{1}{v} \right)^{0.35} \right\}$$

c.g.s. units per foot run, and on dividing by 4.45×10^5, the value of F in lbs. force per foot run. The following are the numerical values of F at speeds used by Froude § :—

Speed.		Force in Lbs. per Foot Run.		
			Froude observed 50 ft. board.	
Ft. per mt.	Cm. per sec.	Calculated.	Last 45 ft.	Last 34 ft.
200	102	0.128	0.104	0.097
300	152	0.270	0.216	0.209
400	203	0.455	0.362	0.353
500	254	0.690	0.536	0.491
600	305	0.962	0.751	0.741

It will be noticed that on this hypothesis the frictional force calculated from the pipe formula comes between 20 and 30 per cent. greater than that found by Froude.

13. Taking now the equivalent cylinder to be of diameter 24.4 cm. in accordance with the stream-line theory,‖ we get for the frictional resistance of a foot of the pipe :—

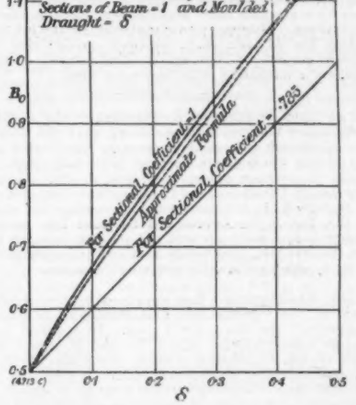
$$F = v^2 \left\{ 2.10 + 12.2 \left(\frac{1}{v} \right)^{0.35} \right\}$$

c.g.s. units. On dividing by 4.45×10^5 we get F in lbs. per foot run, and the following numerical values :—

Speed.		Force in Lbs. per Foot Run.		
			Froude observed 50 ft. board.	
Ft. per mt.	Cm. per sec.	Calculated.	Last 45 ft.	Last 34 ft.
200	102	0.105	0.104	0.097
300	152	0.220	0.216	0.209
400	203	0.374	0.362	0.353
500	254	0.560	0.536	0.491
600	305	0.785	0.751	0.741

The results calculated from the pipe formula and constants exceed those observed by Froude for the last 34 ft. by about 5 per cent., but the agreement* is sufficiently close to show that there is in all probability an intimate connection between the frictional resistance of the after portion of a long towed body and that of water flowing through a pipe. Till the process by which frictional forces are introduced in eddying motion are better understood, and a general theory has been developed,† it will be impossible to make use of this connection to the best advantage. In the meantime it seems desirable that experiments should be made with a view to determining to what extent the propositions with regard to bodies of equivalent resistance in stream-line motion may be carried over to eddying motion, and, if it should prove they cannot be, to determine the corresponding propositions for eddying motion.

Fig. 5.



PROPERTIES OF A TWO-POWER FORMULA FOR SKIN FRICTION OF LONG PARALLEL MID-BODIES.

14. The success of the formula :

$$F = \pi l d v^2 \left\{ a + b \left(\frac{\nu}{d v} \right)^n \right\} \quad . \quad . \quad (3)$$

with the values of the constants a, b, and n taken from the experiments on the flow of fluid through smooth pipes in reproducing the values found by Froude and by Tideman for the resistances of boards towed in water, makes it advisable to trace still further the consequences of adopting an expression of this kind for the frictional resistance of long parallel mid-bodies of ships and of their tank models.

15. In the first instance, consider the laws of variation of resistances of the long body and its model with the speed.

If a small change δv is made in the speed, the resulting small change δF in the resistance may be found from the equation :—

$$\frac{\delta F}{F} = \frac{1 + (1 - \frac{1}{2}n) \left(\frac{b}{a} \right) \left(\frac{\nu}{d v} \right)}{1 + \left(\frac{b}{a} \right) \left(\frac{\nu}{d v} \right)} . 2 . \frac{\delta v}{v} \quad . \quad (7)$$

On substituting the values of the constants for water as found in pipe experiments, this becomes :—

$$\frac{\delta F}{F} = \frac{1 + 14.6 \left(\frac{1}{d v} \right)^{0.35}}{1 + 17.7 \left(\frac{1}{d v} \right)^{0.35}} . 2 . \frac{\delta v}{v}$$

Taking the case of a 26-knot liner for which the diameter of the equivalent circular section of the same resistance is, say, 90 ft., and its tank model of diameter, say, 1.8 ft., and speed 3.68 knots, we have for the model $d = 55$ cm. $v = 184$ cm. per second. Thus :—

$$d v = 1.01 \times 10^4 \text{ and } (d v)^{0.35} = 25.2$$

Hence for the model :—

$$\frac{\delta F}{F} = \frac{1 + \left(\frac{14.6}{25.2} \right)}{1 + \left(\frac{17.7}{25.2} \right)} . 2 . \frac{\delta v}{v} = 1.85 \frac{\delta v}{v}$$

This implies that for small variations of speed of the model in the neighbourhood of 3.68 knots the frictional resistance will vary as the 1.85th power of the speed, a result in fair agreement with experiment.

For the ship $d = 2745$ cm., $v = 1300$ cm. per second. Thus :—

$$d v = 3.57 \times 10^5 \text{ and } (d v)^{0.35} = 196$$

Hence for the ship :—

$$\frac{\delta F}{F} = \frac{1 + \left(\frac{14.6}{196} \right)}{1 + \left(\frac{17.7}{196} \right)} . 2 . \frac{\delta v}{v} = 1.97 . \frac{d v}{v}$$

This implies that for variations of the speed of the ship in the neighbourhood of 26 knots the frictional resistance will vary as the 1.97th power of the speed; that is, for large high-speed vessels the frictional resistance will vary very nearly as the square of the speed.

It remains to be seen whether the experience of naval engineers is in favour of the square of the speed for the law of frictional resistance of the vessels themselves. It is the law on which the validity of the Admiralty formula for the horse-power and the existence of the Admiralty coefficient depend.

16. In the second place, we may consider what is implied by the two-power formula as to the variation of the frictional resistances of ship and model with temperature, or with salinity of the water.

If, owing to either cause, ν increases by the small amount $\delta \nu$, the small change δF in the frictional resistance may be found from the equation :—

$$\frac{\delta F}{F} = \frac{n}{1 + \frac{a}{\left(\frac{\nu}{d v} \right)^n}} \left(\frac{\delta \nu}{\nu} \right) \quad . \quad . \quad . \quad (8)$$

Taking the change from $\nu = 0.0114$ at 15 deg. Cent. to $\nu = 0.100$ at 20 deg. Cent., $\delta \nu = -0.0014$ and $\frac{\delta \nu}{\nu} = -0.123$ for 5 deg. Cent. or 9 deg. Fahr. Substituting in the formula the values of the constants found for the flow of water in smooth pipes we have :—

$$\frac{\delta F}{F} = - \frac{0.0430}{1 + 0.0564 (d v)^{0.35}}$$

For the model of the fast liner previously considered this gives with $(d v)^{0.35} = 25.2$

$$\frac{\delta F}{F} = - \frac{0.0430}{1 + 0.056 (25.2)} = - 0.018 ;$$

that is, 1.8 per cent. for 5 deg. Cent. or 9 deg. Fahr. At lower speeds the decrease would be greater, and in fair agreement with those found by Froude and by Baker* for models of about this size.

In the same way for the ship itself $(d v)^{0.35} = 196$. Hence :—

$$\frac{\delta F}{F} = - \frac{0.0430}{1 + 0.056 (196)} = - 0.0036 ;$$

that is, 0.36 per cent. for 5 deg. Cent. or 9 deg. Fahr.

This decrease is insignificant in comparison with the much larger decrease found for the model. Thus, although the temperature effect is appreciable in tank experiments, and makes it necessary to reduce results to a standard temperature, the effect of temperature on the frictional resistance of the ship itself is inappreciable.

17. The change from fresh to sea water involves an increase of ν at 15 deg. Cent., from 0.0114 to 0.0116, which is nearly equal to that due to a decrease of 0.7 deg. Cent. or 1.2 deg. Fahr. in the temperature of fresh water. Thus the only appreciable change in the frictional resistance of a ship on passing from fresh to salt water would be that due to the change of draught.

It remains to be seen how far these deductions from the two-power formula for the frictional resistance are in accord with the experience of naval engineers.

ON THE FRICTIONAL RESISTANCE DUE TO KEELS IN STREAM-LINE MOTIONS.

18. When a plane surface of considerable extent is in motion in its own plane through a fluid, at a speed small enough to generate only stream-line motion, in the surrounding fluid, the addition of a thin keel to the surface, with its length along the direction of motion, increases the frictional resistance to the motion by an amount which has been recently calculated. If A (Fig. 6) is the outer edge of the section of the keel, B its inner edge, and P a point on the plane surface some distance from B, and in a plane perpendicular to that of the keel, the frictional resistance of the surface A B of the keel and the surface B P of the plane, is equal to that of a strip of the original surface of breadth $\sqrt{(A B + B P)}$, so long as the keel is thin or is only thickened at the inner edge B.†

When the keel is of considerable thickness, O (Fig. 7) being the centre of its lower surface, A the outer edge, B the inner edge, and P a point on the plane surface,

* Rayleigh, Phil. Mag., 8, page 66 (1904).

† Zahm, Phil. Mag. 8, page 58.

‡ Froude, Report, British Association, 1872, page 118.

§ The numbers quoted from Froude are taken from the curves A, C, and D of Plate IV., page 120. B.A. Report, 1872.

‖ Kent and Baker, Trans. Inst. Nav. Arch., vol. xlv., page 37, have recently shown that the frictional coefficient f in formula (1), page 526, is greater for models of ships than for flat boards. The stream-line theory makes it $\frac{4}{\pi} = 1.28$ times as great for a circular section as for a flat board.

* With Tideman's constants, as quoted in Hütte, 21st Edition, vol. ii., page 745, for painted surfaces, the frictional force per foot run on the last 30 ft. of a 60-ft. board would be about 3 per cent. higher than the values given above for the last 34 ft. of Froude's board.

† Dr. Gümbel, Jahrbuch der Schiffbautechnischen Gesellschaft, vol. xiv. (1913), page 393, suggests that the relation between the translatory and vortex motions provides a sufficient explanation.

* Baker, Trans. N.E. Coast Inst. Eng., vol. xxxii., page 41, 1915.

† Lees, Roy. Soc. Proc., A., vol. xcii., page 156, 1915.

the frictional resistance of the surface between O and P is equal to that of a strip of the original surface of width :—

$$\sqrt{\{(O A + B P)^2 + A B^2 + 1.77 O A^{0.42} A B^{0.18}\}} *$$

in all cases in which P is a considerable distance from B and O A does not exceed twice A B.

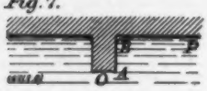
The inner edge of the keel at B may be thickened considerably without seriously affecting the result.

When the surface to which the keel is attached is cylindrical instead of plane, the propositions still hold if the distances B P are measured along the curved surface and the radius of curvature of the surface is large compared to the depth of the keel.

19. When we pass from speeds which give only stream-line motion in the fluid to speeds high enough to produce eddying or turbulent motion, we get little guidance from theory. Froude's experiments of the effects of bilge

Fig. 6.

Fig. 7.



keels on the Greyhound indicated that they increased the frictional resistance to a small extent only. This is in keeping with what would be expected from the stream-line theory, but that theory cannot with any confidence be extended to cases involving eddying motion without further experimental work. It is, however, probable that the additional frictional resistance due to a keel is at low speeds considerably less than the value as usually calculated from the added surface.

20. The foregoing columns serve to emphasise the fact that while in the case of stream-line motions the general theory is capable of giving us interesting and important results with regard to the frictional resistances of long bodies, in the case of eddying or turbulent motions the absence of a general theory forces us to use empirical formulæ over ranges much wider than are covered by the original measurements. It is of prime importance that further measurements should be made on bodies which lend themselves to simple theoretical treatment in order to build up a satisfactory theory. In the meantime it seems justifiable to make what use we can of the propositions established for stream-line motions, and of the connection between the frictional resistances of pipes and of long bodies towed through fluids, when the motion in the fluid is eddying or turbulent.

Sault Ste. Marie.—The Great Lakes Power Company, Limited, an American concern, has purchased the water power plant of the Algoma Steel Corporation on St. Mary's River Falls, including all rights now held for water for further development. This practically involves a control of all the power apportioned to Canada which may be developed on St. Mary's Falls. There is now about 15,000 horse power, and the "deal" includes a contract for increasing this to 30,000 horse power, to be ready for use by January 1, 1918. The development of this further power will cost approximately 2,000,000 dols.

Leakage from Water Mains.—In an article recently published in the Journal of the New England Water Works Association, Mr. A. H. Smith observes that the leakage from water mains is usually surprisingly high. The general opinion of water-works men is, he says, that from 30 per cent. to 40 per cent. of the total supply is lost by leakage. The leaks may be in the underground mains, in broken or abandoned service pipes, or in faulty domestic fittings. In a test of mains at Medway, Mass., having lead joints and working under an 80 ft. head, the underground leakage amounted to 20,800 gallons (U.S.) in the 24 hours, which was equivalent to 1.58 gallons per lineal foot of the joint. As a remedy, Mr. Smith expresses the opinion that either some better material than lead must be found or more care must be taken in making the joints. He considers that a loss not exceeding 1 gallon per day per ft. of joint under 100 lb. pressure may be regarded as satisfactory.

A Large Drainage Plant in California.—In a recent issue of the *Journal of the American Society of Mechanical Engineers*, Mr. G. C. Noble describes a large centrifugal pumping plant installed in the Sacramento Valley, California. The area drained covers 66,000 acres. The maximum flood level is 29 ft. above datum, and during winter time the entire district (prior to the establishment of the works) was under water to a depth of, in some cases, as much as 20 ft. To drain it, levees of a total length of 70 miles were constructed around the area. The whole of the space included was arranged to drain to one point, where an electrically driven centrifugal pumping plant has been installed. This consists of six 50-in. centrifugal pumps, each coupled to an 800-horse-power electric motor. These pumps can each deliver 175 cub. ft. per sec. against a head of 29 ft. The current for the motors is taken from the mains of a power company at 60,000 volts, which is transformed down to 2200 volts before use.

* *Loc.*, page 157.

NOTES FROM THE UNITED STATES.

Philadelphia, May 17, 1916.

The past week has brought out quite a number of inquiries for munition material from various European countries; an estimate as to the volume is impossible. The pressure for munitions, while urgent, is for relatively early deliveries; there is nothing to indicate any weakening in prices. The demand is especially urgent for round-cornered billets for export; it is probable that nearly all the business seeking acceptance will be taken care of. The Pennsylvania Company has ordered from the Baldwin Company of Philadelphia 75 locomotives; other locomotive orders this week number about 60. Railroad demand has largely subsided, as nearly all rail requirements for this and next year have been covered. For other than rails, such as plates and structural steel, there is quite an active demand. Premium prices prevail. In the pig-iron market activity is only moderate, owing to recent excessive demands; all indications point to continued activity on the part of buyers to the limits of capacity. The steel industry is in a sense settling down. The far-oversold mills are unwilling to extend engagements at present; their policy may be overcome through the insistence of urgent buyers, who may feel that it is necessary to know what the material will cost them to complete the contracts that they have recently taken or soon will be obliged to take. Steel merchant vessels now building or under contract number 368, of more than 1,000,000 tonnage. Every shipyard, it is unnecessary to say, is working to capacity, with business booked far ahead. Cargo vessels and bulk oil vessels constitute much of the work in hand. Two hundred and twenty vessels building are for salt water, 147 for lakes and rivers. The New York Subway has just put out an inquiry for an additional supply of 20,000 tons of steel, making 35,000 tons now under inquiry. The Midvale Steel Company will buy 3500 tons for a machine shop, and the Pennsylvania 2500 tons for bridges. Belgium wants material for 100 lift bridges calling for 25 tons each, to span canals; this is the second inquiry of that kind. The volume of general business is increasing at an enormous rate.

The Cost of Illness to Industry.—As a result of unnecessary sickness and accidents, says the *Iron Age*, the 33,000,000 industrial workers in the United States lost about 284,000,000 working days each year, as a result of sickness alone, according to Dr. Donald B. Armstrong, Director of the Department of Social Welfare, of the New York Association for Improving the Condition of the Poor. He figures the financial loss, including wages, loss to industry and the medical cost, at nearly 500,000,000 dols., and yet at least one half of the sickness, he says, was from strictly preventable causes.

The Mercantile Year-Book.—We have received a copy of the "Mercantile Year-Book and Directory of Exporters" for the current year. It is edited by Mr. Walter Lindley-Jones, F.R.G.S., and is issued at the price of 10s. by Messrs. Lindley-Jones and Butler, 16, St. Helen's Place, Bishopsgate, E.C. It gives the names and addresses of the exporters of London in street order; the names of importers in the British colonies and foreign countries, with their representatives and buying agencies in Europe; a directory of the classes of goods shipped from London, with the names of the shippers; the merchant exporters of London, with their addresses and the markets with which they deal. Similar information is given in regard to British provincial towns and Continental towns. The feature of the present edition is the inclusion of a black-list of enemy firms abroad; a list of traders in China and Siam with whom trade is permissible; a list of Belgian firms temporarily established in this country, and lists of Italian and Swiss exporters.

Education on Naval History and the Command of the Sea.—The President of the Board of Education received recently a deputation from the Navy League, which waited on him to urge the profound importance of making the teaching of general principles of Sea Power and the main outlines of Naval History an essential part of National Education. In replying to the representations of the members of the deputation, Mr. Henderson expressed his cordial sympathy with the general objects of the League, and said that the Board were impressed with the importance of the subject which the deputation had come to advocate. He explained that the separation of functions between the Board and the Local Education Authorities made it inevitable that the immediate responsibility for the details of curriculum and methods of teaching should fall upon the Local Authority, the Board exercising control principally by inspection and suggestion. He indicated the special difficulty of extending the curriculum, especially at the present time when so many thousands of teachers had joined the Forces. The school life of children was much shorter than he would like to see it, and so much time was necessarily spent on giving them a thorough mastery of the elementary subjects as to leave comparatively little opportunity for more advanced topics. He emphasised, however, the fact that in the vast majority of schools instruction in the Naval History of the country and in the growth of the Empire was already being given, much of it in the way which appealed most strongly to children, by lessons on the lives of great naval commanders. He had no doubt that the teachers generally were availing themselves of the opportunities given them by the war to strengthen and deepen the children's understanding of the work of the Navy as the principal defence of our liberty and prosperity, and he promised to give careful consideration to any practical proposals which the League might care to lay before him.

NOTES FROM SOUTH YORKSHIRE.

Sheffield, Wednesday.

South Yorkshire Coal Trade.—The market has not undergone any pronounced change during the week, though there have been slight variations in the different sections of the trade. House coal is now in much improved demand, evidently as the result of an effort to lay in stocks. Collieries and agents are rather pleased at the change in view of the fact that it will tend to keep this class of customers from adding to their difficulties in the approaching busy season. Prices are nominally unchanged, being officially returned at the maximum. Inquiries for gas fuel are on the usual large scale, and considerable tonnage is going away to inland works for contract orders. Manufactories readily absorb all the available supplies of their brands of coal. The fine weather has given pits the opportunity to produce the maximum output, and many contract arrears have been overtaken. Steam hards are still a difficult market. Swedish steel-makers persist in their inquiries for South Yorkshire hard coal for their furnaces, and good figures are quoted. Chiefly owing to the export restrictions, little tonnage is being secured. Practically the whole of the export trade is conserved for the requirements of French, Russian, and Italian consumers. Recent statistics show that a greater quantity is going away weekly to the allied countries and, further, that the representations on the question of the excessive quotations have not been without some effect. The prices are still well ahead of those for the home trade, but not so extravagant as obtained during the earlier part of last month. Very little fuel of any description is to be had on the open market. Coke is being used on an increased scale, and good prices are forthcoming. Quotations :—Best branch hand-picked, 20s. 6d. to 21s. 6d.; Barnsley best Silkstones, 17s. 6d. to 18s. 6d.; Derbyshire best brights, 17s. 6d. to 18s. 6d.; Derbyshire house coal, 16s. to 17s.; best large nuts, 15s. 6d. to 16s. 6d.; small nuts, 15s. to 16s.; Yorkshire hards, 16s. 6d. to 17s. 6d.; Derbyshire hards, 16s. to 17s.; best slacks, 12s. to 13s.; seconds, 10s. 6d. to 11s. 6d.; smalls, 8s. to 9s.

Iron and Steel.—The steel output is increasing apace with the advent of the new facilities for production, and munition works are still absorbing the greater part of it. The British billet problem is the chief topic at the moment, and consumers are troubled more with the question of supply than with the one of price. Bessemer acids are marked at 13*l.* 10s. to 14*l.*, and Siemens 15*l.* to 16*l.* For new basic hard 11*l.* 2s. 6d. is being paid, and for basic soft 10*l.* 7s. 6d. South Yorkshire "Crown" bars are at the maximum figure of 13*l.* 15s. net. The labour problem is causing delay, and irregular working at the rolling mills and forges, and this, coupled with the increased cost of fuel, is having an adverse effect upon production. The pig-iron makers have also suffered by the withdrawal of labour for army purposes, but in view of the representations made by the trade, the military authorities are releasing numbers of men to enable them to return to the furnaces and the foundries. The common iron maximum prices may undergo some change in the near future, for the existing tariff only holds good until the end of the current month. An advance in price is almost inevitable, especially as here too the fuel problem is not without considerable adverse influence. In view of the enormous amount of steel-melting scrap, turnings and borings dealt with in the Sheffield district week by week, the announcement that the Government may formulate a scheme regulating prices has aroused a good deal of interest. Merchants are chary about expressing opinions on the subject, for they do not yet seem to have been consulted in the matter. Some hold that the intricate nature of the trade and the multiplicity of dealers do not permit of the application of the proposed alteration. The tool trade enjoys a busy period, but the shortage of hand tools of every description remains pronounced. Files are very scarce. Six months' orders are on the books of some large firms, and the demand is increasing, with little prospect of an immediate acceleration of output. The home market is served first, and this position has led to inconvenience on the part of neutral would-be customers. Engineers' tools, pliers, nippers, spanners, turnscrews, hammers, &c., are being freely asked for. The Government requirements total an enormous figure, War Office and Admiralty orders being very large. Sheffield metal-spinners are making excellent progress in turning out the newest part of the soldier's equipment, the steel helmet, and huge quantities have been delivered. Several important municipal tramway undertakings have placed large contracts here for tramway points and crossings, special junction work, &c. This branch of manufacture is classed "A1" war work at the Munitions Ministry by reason of the important functions tramways discharge in conveying the workers from distances to work and back. The attention given by the Government departments to the position of Sheffield export trade has resulted in relaxing certain export regulations which had operated rather harshly, and the latest figures furnished by the Cutlers' Company reveal that bona-fide manufacturers are reaping a good harvest in this direction. Good markets for Sheffield materials and manufactures are found in the Colonies, United States, and South America. The latest overseas orders are for steel, files, saws, and cutlery.

Heavy Rails for the Pennsylvania Railroad.—The Pennsylvania Railroad have ordered 120,000 tons of a rail weighing 130 lb. per yard for use on their lines east of Pittsburg. The rail is 6½ in. high, 5½ in. wide at the base, whilst the top table is 3 in. wide by 2 in. thick.

NOTES FROM THE NORTH.

GLASGOW, Wednesday.

Glasgow Pig-Iron Market.—The first change for a number of days took place in the pig-iron warrant market on Wednesday, when buyers advanced their quotations to 92s. 6d. per ton, but again without any effect on the part of sellers. Conditions remained unchanged on Thursday, but on Friday buyers' quotations were advanced to 95s. per ton, but still no business was done. On Monday buyers and sellers alike were absent, a state of affairs which continued yesterday (Tuesday) also. The market is now closed for the present.

Scotch Steel Trade.—Without doubt the steel trade in the West of Scotland continues to flourish amazingly, and practically nothing could exceed the amount of business which is being put through. The extreme pressure for all classes of steel for Government purposes certainly constitutes a series of records, and at the moment the demand for the delivery of shell bars and light sheets is taxing the energies of makers to the utmost extent. There is also a very fair demand for light sections, required directly or indirectly for the prosecution of the war. It is satisfactory to note that quite a visible improvement has taken place in connection with ordinary mercantile business for home delivery, and that there is no falling-off in the export trade, shipments to France being well to the fore, despite the stringent restrictive ruling which was expected to have a very serious effect on the oversea trade. Government demands, however, continue to be particularly heavy, with the result that steelmakers are doing all in their power to increase the output. With it all it means a decided scarcity of steel available for general purposes, and so far as can be seen in the meantime there is little prospect of any change taking place until after peace has been declared. Prices are again on the upward grade, and ship-plates are now quoted 14*l.* per ton or thereabouts; boiler-plates, 14*l.* 5*s.*; and angles, 14*l.*, these figures being for export business, with home rates as per arrangement fixed by Government.

Malleable-Iron Trade.—There is a very gratifying and persistent demand for malleable iron, local makers finding their order-books full and their deliveries behind-hand rather than otherwise, owing to the great strain made upon their output by Government. So great is this in fact that the light mills are having to yield their entire production to meet Government's clamant requirements, leaving little else than the heavier sections at the disposal of ordinary mercantile consumers, in consequence of which new business is quite off in the meantime. In this way the export trade is suffering also. Prices, however, keep firm, and "Crown" bars are still quoted about 14*l.* or 14*l.* 2*s.* 6*d.* net for approved specifications.

Scotch Pig-Iron Trade.—It would almost seem as if the continued standstill in the Glasgow pig-iron warrant market were but the beginning of the end, so far as speculation is concerned. Otherwise the greatest activity prevails, and every ton produced by the makers finds a ready market; indeed, they have a decided difficulty in maintaining the output to the required level. Stocks, therefore, are gradually coming down. The extra-ordinary home demand for hematite and foundry qualities is preventing much export, although licences are being granted with much freedom for shipments of pig-iron to France, Italy, and some of our own Colonies, all, of course, either directly or indirectly on Government account. No change of price has been reported over the week, and makers (No. 1) iron is still quoted as follows:—Clyde, Calder, Summerlee, and Langloan, 130*s.* per ton; Gartsherrie, 131*s.* 6*d.* (all shipped at Glasgow); Eglinton, 126*s.* 6*d.*, Glengarnock, 130*s.* (both at Ardrossan); Dalmellington, 126*s.* 6*d.* (at Ayr); Shotts and Carron, 130*s.* (both at Leith).

Glasgow Fair Holidays.—In view of the suggestion put forward by the Minister of Munitions regarding the holidays of those engaged on Government work, there is every prospect that the annual Fair Holidays, occurring in the middle of July—and which dominate the industrial operations of the West of Scotland—may most probably be postponed until some weeks later. Meantime, however, no definite decision has been arrived at, although the prospect is being discussed with considerable anxiety.

Scotch Shipbuilding in May.—Some little improvement took place during the month, which, although it does not prove much, is, to a degree, satisfactory. Even yet, however, no evidence is shown regarding the arrangements suggested by Government to consider the building of merchant vessels as "war work," and certainly during May no such contracts have been placed. The aggregate tonnage for the month—24,614 tons for 10 vessels—causes May to rank as one of the best months for the year as far as it goes, and compares favourably with May, 1915, but it is still much below the average. The following table shows the production of the four chief rivers:—

Clyde.		Forth.		Tay.		Dee.	
Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.
6	21,970	2	2224	—	—	2	420

Of the Clyde tonnage, three of the six vessels were cargo steamers launched from one Port Glasgow yard.

TRADE DURING AND AFTER THE WAR.—We have received from the London Chamber of Commerce a copy of the Second Report presented to the Council of the Chamber by the Special Committee on Trade During and After the War, and which was adopted by the Council at a special meeting held on the 25th ult.

NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

MIDDLESBROUGH, Wednesday.

The Maximum Price of Cleveland Pig.—The principal topic of conversation this week is the coming advance of the maximum price of Cleveland pig-iron for home consumption. The announcement is made that after the end of next month the maximum for No. 3 will be raised from 82*s.* 6*d.* to 87*s.* 6*d.* Though, as yet, there is no official statement to this effect, traders regard the movement as assured, and the announcement has caused no surprise. Makers complain that with present cost of production the existing maximum is unremunerative, and declare that they have quite expected an advanced maximum price to be fixed.

The Output of Pig-Iron.—With the scarcity of pig-iron becoming more pronounced, and as a consequence restrictions on export more severe so as to meet home requirements better, the Government is exerting much pressure on makers to increase the output. For this purpose the Government offer to provide men and material, and as a result steps are being taken to blow in more furnaces. An additional furnace is to be started on basic iron, one or two are to be relighted for the production of hematite, and it is hoped that the manufacture of Cleveland pig will also be increased. The number of blast-furnaces at present in operation on the North-East Coast stands at 69, of which 28 are running on Cleveland pig, 30 are turning out hematite, and 11 are making special kinds of iron.

Stocks of Pig-Iron.—The stock of Cleveland pig-iron in the public warrant stores now stands at 33,073 tons, of which 31,547 tons are No. 3 quality and 1526 tons other qualities of iron deliverable as standard. Since the beginning of May the stock has been reduced by 7332 tons, 6398 tons of No. 3 and 934 tons of standard iron having been withdrawn.

The Cleveland Iron Trade.—There is little passing in Cleveland pig. Buyers are keen, but they experience the greatest difficulty in placing orders. It is useless to attempt to do foreign business, and the export quotation of 100*s.* for No. 3 Cleveland pig is purely nominal. For home consumption No. 3 is selling at 82*s.* 6*d.*, and that price also rules for No. 4 foundry and No. 4 forge.

Hematite Iron.—East Coast hematite pig is practically unpurchaseable. Not only have makers no iron to dispose of for early delivery, but they have sold their output a month or two ahead, and the promised increased production is eagerly awaited. There are no stocks of hematite. Licences for export to neutral countries are quite unobtainable, and even permits to our Allies are very sparingly granted. Distributions to home consumers are allotted with care by the committee appointed for that purpose. The export price of Nos. 1, 2 and 3 is nominally 140*s.* and upward. For home use the price of mixed numbers keeps at 122*s.* 6*d.*

Coke.—Demand for coke for local use is good and promises to improve. Supply is anything but plentiful. Average blast-furnace kinds keep at 28*s.* at the ovens, and up to 30*s.* 6*d.* at the ovens is named for qualities low in phosphorus.

Foreign Ore.—As regards foreign ore the attitude of mineowners abroad is such as to justify anticipation of further advance in prices. Rubio of 50 per cent. quality is fully 18*s.* f.o.b. at port of despatch, and in the ordinary way in the open market the freight Bilbao-Middlesbrough is 18*s.* 6*d.* making the ex-ship Tees price 36*s.* 6*d.*; but consumers manufacturing iron for home use are privileged to arrange, through the Government, freights from Bilbao at 17*s.*, making the ex-ship Tees price of best Rubio 35*s.* Excellent supplies of foreign ore are coming steadily to hand. Imports to the Tees for May amount to 195,178 tons.

Manufactured Iron and Steel.—War work continues to monopolise the attention of manufacturers of finished iron and steel, and the Government is still pressing for deliveries. The consequence is that the rather numerous private inquiries in the market attract little notice. Quotations, all round, are strong. Common iron bars are 13*l.* 15*s.*; best bars, 14*l.* 2*s.* 6*d.*; best best bars, 14*l.* 10*s.*; packing iron (parallel), 10*l.*; packing iron (tapered), 11*l.* 10*s.*; iron ship-plates, 11*l.* 10*s.*; iron ship-angles, 13*l.* 15*s.*; iron ship-rivets (¾ diameter), 16*l.* 10*s.*; iron ship-rivets (⅝ diameter), 17*l.* 10*s.*; steel bars (no test), 14*l.* 10*s.*; steel ship-plates, 11*l.* 10*s.*; steel ship-angles, 11*l.* 2*s.* 6*d.*; steel ship-rivets (¾ diameter), 17*l.* 10*s.*; steel ship-rivets (⅝ diameter), 18*l.* 10*s.*; steel sheets (singles), 18*l.* 10*s.*; steel sheets (doubles), 18*l.* 15*s.*; steel joists 11*l.* 10*s.*; and heavy steel rails, 10*l.* 17*s.* 6*d.*

Manufactured Ironworkers' Wages.—The average net selling price of iron rails, plates, bars, and angles for the two months ended 30 April last has just been certified at 11*l.* 9*s.* 5.57*d.* by the accountants to the Board of Arbitration for the Manufactured Iron and Steel Traders of the North of England, as compared with 10*l.* 14*s.* 4.60*d.* for the previous two months, and in accordance with sliding-scale arrangements wages for the months of June and July are advanced by 9*d.* per ton on puddling work and by 7½ per cent. on all other forge and mill work.

Shipments of Iron and Steel.—Shipments of iron and steel from the Tees during May reached 108,818 tons, 67,880 tons being pig-iron, 4564 tons manufactured iron, and 36,374 tons steel. Of the pig despatched 64,808 tons went abroad, and 3072 tons coastwise; of the manufactured iron 1265 tons went foreign and 3299 tons coastwise; and of the steel cleared 35,917 tons went abroad and 457 tons coastwise. France was again the largest customer for both pig iron and steel, receiving 44,067 tons of the former and 25,407 tons of the latter. Other principal pig-iron importers were Spain, 4970 tons; Japan, 4162 tons; America, 3959 tons; and Italy, 3751 tons; whilst other chief customers for steel were:—Japan, 5132 tons and India, 1192 tons. The heaviest importers of manufactured iron were India, 289 tons; the Straits, 214 tons; and Japan, 204 tons.

NOTES FROM THE SOUTH-WEST.

Cardiff.—In consequence mainly of the uncertainties attending the proposed limitation of coal prices to France, business in steam coal has been restricted within narrower limits, both buyers and sellers withholding their hands for the time being. The shortage of coal remains, however, as decided as ever, and there has been no disposition on the part of coalowners to reduce prices to ports not confined within the limitation area. It is anticipated that prices outside the limits of the official scheme are more likely to advance than to show weakness. The best Admiralty large steam coal has been, to some extent, nominal; secondary qualities have made 54*s.* to 55*s.* per ton; Monmouthshire Black Veins, 54*s.* 6*d.* to 55*s.*; ordinary Western Valleys, 54*s.* to 54*s.* 6*d.*; Eastern Valleys, 50*s.* to 52*s.* 6*d.*; best bunker smalls, 32*s.* to 33*s.*; and cargo smalls, 25*s.* to 28*s.* per ton. In bituminous coal, best households have made 23*s.* to 24*s.* at the pits. No. 3 Rhondda large, 57*s.* 6*d.* to 60*s.*; smalls, 35*s.* to 37*s.* 6*d.*; No. 2 Rhondda large, 47*s.* 6*d.* to 49*s.*; and No. 2 smalls, 25*s.* to 28*s.* per ton. The latest quotation for patent fuel has been 50*s.* to 55*s.* per ton. Special foundry coke, for export, has been quoted at 62*s.* to 65*s.*, good foundry coke at 60*s.* to 62*s.* 6*d.*, and furnace coke at 50*s.* to 55*s.* per ton.

Welsh Coal for France.—Welsh colliery-owners have shown more disposition to support the coal-price limitation policy of the Government in the case of France; and at the same time they have urged that the limitation prices must be fixed at a considerably higher level in view of the heavy increase in working costs. The colliery proprietors have appointed a committee with full powers to deal with the subject. The committee will meet representatives of other coal-owners' associations in London; they will also have an interview with Mr. Runciman. They suggest a limitation of 10*s.* per ton above pre-war quotations and they ask for reciprocal arrangements with France for securing cheaper pit-wood. The new prices arranged between the English and French Governments are considerably above those first put forward by Mr. Runciman; but they are still much below current market quotations. A feature of the proposed scheme is that all orders for coal from France will pass through a central office in Paris, which will forward them to local committees in the various coal districts of the United Kingdom; the local committees will distribute the orders and arrange for the shipping required. Cardiff prices to France have been limited as follow: Large steam coal, 30*s.* per ton net; colliery smalls, 20*s.* per ton net; washed nuts, 30*s.* per ton net; washed beans, 28*s.* per ton net; and washed peas, 27*s.* 6*d.* per ton net. Swansea prices for anthracite have been limited thus: Large, 30*s.* per ton net; small, 20*s.* per ton net.

Western Trade Matters.—The directors of the Tredegar Iron and Coal Company, Limited, recommend a dividend and bonus of 15 per cent. upon the A and B shares in the company for the past year, free of income tax. The dividends for the last five years have been as follow: 1912, 6 per cent.; 1913, 10 per cent.; 1914, 12½ per cent.; 1915, 12½ per cent.; and 1916, 15 per cent.—The Rhymney Iron Company, Limited, gives its ordinary proprietors a dividend of 5 per cent. for 1915, 10,118*l.* being carried to the credit of 1916–17. The distributions for the five years ending with 1916 inclusive have been as follow: 1912, nil; 1913, 4 per cent.; 1914, 5 per cent.; 1915, nil; and 1916, 5 per cent. The 5 per cent. involves a distribution of 30,000*l.* The company's output of coal for the past year was 6,021,482 tons; the falling-off of 82,212 tons was due to the further loss of labour occasioned by the war. There was also a decrease of 6062 tons last year in the production of coke; this was principally owing to the re-building of the ovens. During the last four months coal prices have ruled very high, but, owing to the heavy requirements of the Admiralty, to which all other contracts have had to be postponed, very little coal has been available for sale at the advantageous rates which have prevailed.—Mr. F. C. Gould, director and manager of the Dulcia Steam Shipping Company, Limited, reports a trading profit for the 10½ months ended March 31 of 30,449*l.*; the dividend for 1915 is at the rate of 25 per cent., 16,049*l.* being carried forward. It has been decided to increase the share capital of the company from 50,000*l.* to 120,000*l.*—The Hazelwood Shipping Company proposes to divide at the rate of 20 per cent. for the past year; the gross freights of the 12 months amounted to 101,769*l.*, and the profits were 53,534*l.* The dividend of 20 per cent. per annum proposed to be paid for 1916 compares with 15 per cent. per annum distributed for 1914 and 1915; 17½ per cent. per annum paid for 1913, and 12½ per cent. per annum paid for 1912.—The Cunard Steamship Company, Limited, has taken over the ships of the Canadian Northern Steamships, Limited, and is taking up the connection which the Royal Line had developed between Bristol and Canada, the Canadian Northern Railway Company operating.

CANADIAN SHIPBUILDING.—A start in shipbuilding has been made at Quebec by the construction of several large ferry-steamers. A large train-ferry at Vancouver is also in hand.

48-IN. CAR-WHEEL BORING-MACHINE.

CONSTRUCTED BY THE NILES-BEMENT-POND COMPANY, ENGINEERS, HAMILTON, OHIO.

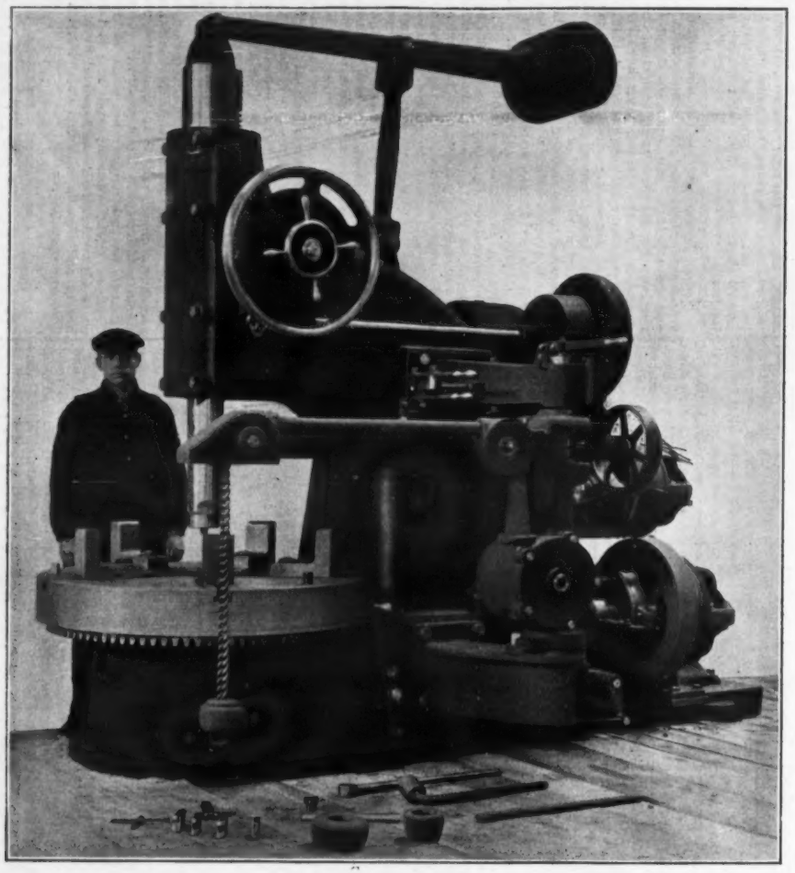


FIG. 1.

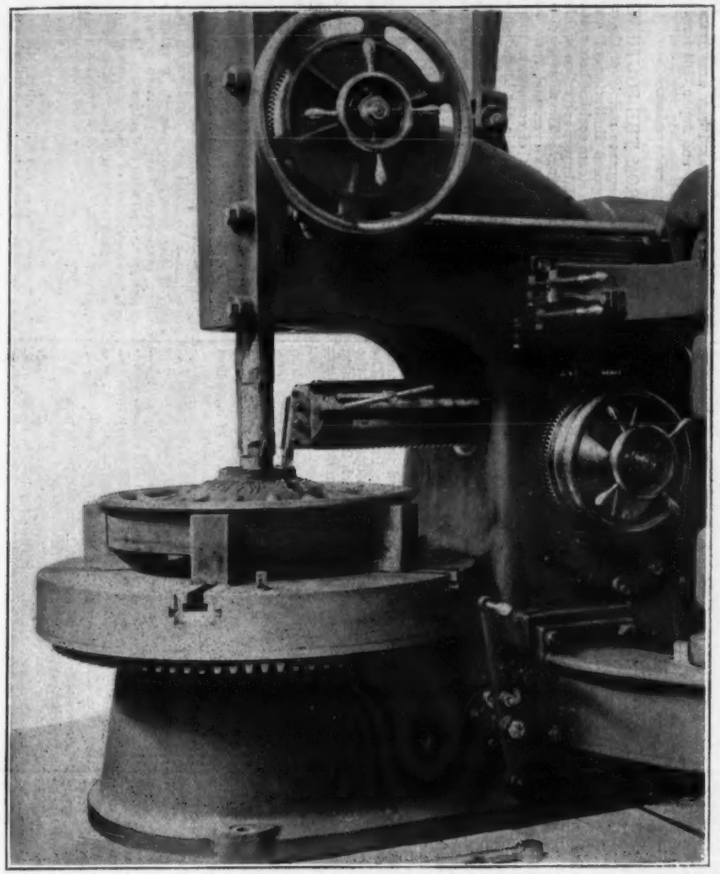


FIG. 2.

WE illustrate in Figs. 1 and 2, on the present page, a 48-in. car-wheel boring-machine, constructed by the Niles-Bement-Pond Company, at their Hamilton (Ohio) Works, for railway rolling-stock manufacture and railway repair-shops. The machine can swing 50 in.; the table has a diameter of 48 in. The chuck can take wheels having from 26 in. to 42 in. diameter on the tread, but wheels of smaller diameter can be taken also by arranging the jaws to reverse. The machine has an ample height from the table to the underside of the frame, and sufficient bar movement to use the long bars; the roughing and finishing tools of these bars are so arranged that the roughing tool goes through the wheel-hub before the finishing tool enters. The table is driven by machine-cut bevel-gearing, and has an annular bearing near its circumference; the table spindle has an adjustable taper bushing, so that the wear in the spindle can be taken up at any time without throwing it out of alignment with the boring-bar. An adjustable collar, with a bearing against the bed, is provided at the bottom of the table spindle to take the upward thrust of the table should it tend to lift. The table is started and stopped by means of a friction-clutch controlled by a lever at the front of the machine. The table is fitted with a self-centring universal chuck, operated by a single motion of a cam-lever, which gives sufficient movement for firmly gripping the wheel. Three shafts, with square heads to receive a wrench, are provided on the table for tightening the chuck; one of these is always within easy reach of the man in charge when the table is stopped. The bar is 8 in. in diameter, and has a 35-in. traverse; it is counterbalanced, and has a rapid traverse by the action of a large hand-wheel. Four feeds are provided for the boring-bar: $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{3}{8}$ in., and $\frac{5}{16}$ in.; the feeds are changed by two levers placed within easy reach of the man in charge. Fig. 2 shows the machine equipped with a hub-facing attachment. The hub-facing bar is fed from the centre towards the outside of the wheel, and may be operated at the same time that the boring-bar is feeding downwards. The hand-wheels for operating the traverse of the bar and the feed-clutch are located on the operating side of the machine. The hub-facing tool-slide is adjusted by means of a socket-wrench. Four feeds for hub-facing are provided: $\frac{1}{16}$ in., $\frac{1}{32}$ in., $\frac{5}{16}$ in., and $\frac{5}{32}$ in. For handling the wheels to and from the table the machine is equipped with either a drum-type crane, as shown in Fig. 1, or with a pneumatic crane. The drum-type crane is controlled by friction-clutches operated by a lever; the crane is so designed that no harm is done if the wheel is lifted to its highest position and the man in charge fails to throw out the clutch.

THE PAY OF RAILWAY MEN IN AMERICA.—The average pay for the fourteen classes into which trainmen are divided in the United States runs from 825 dols. per year up to 2041 dols. All these classes are now asking for an advance of 25 per cent. under the guise of a demand for an eight-hour day.

THE ELECTRIFICATION OF THE SHILDON-NEWPORT BRANCH, NORTH-EASTERN RAILWAY; SUB-STATIONS AT AYCLIFFE AND ERIMUS.

MESSRS. MERZ AND McLELLAN, MM. INST. C.E., LONDON, ENGINEERS.

(*For Description, see Page* 521.)

Fig.36.

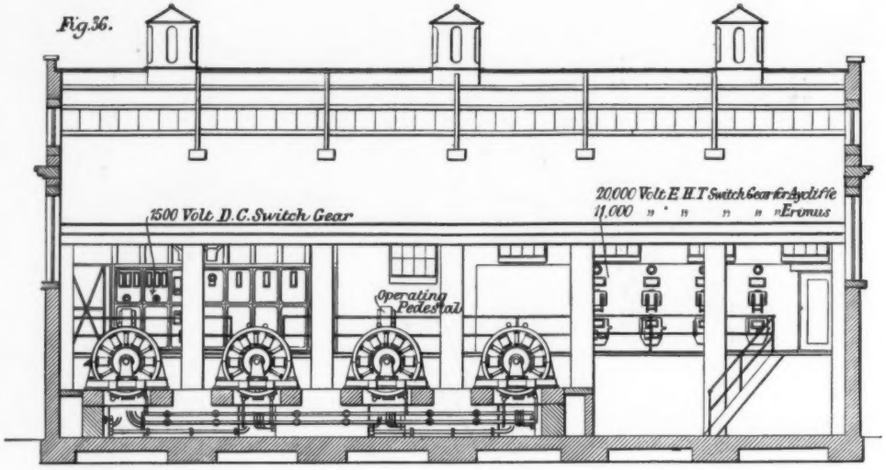


Fig.37.

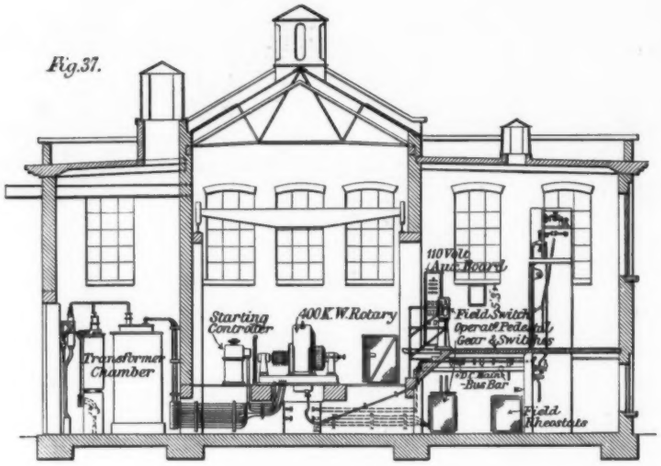


Fig.38. PLAN AT GALLERY LEVEL

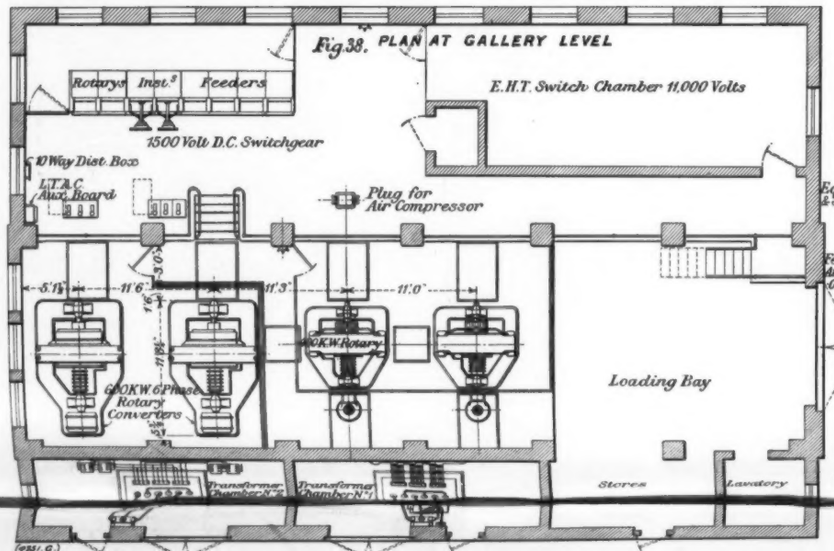


Fig.39. PLAN UNDER FLOOR LEVEL

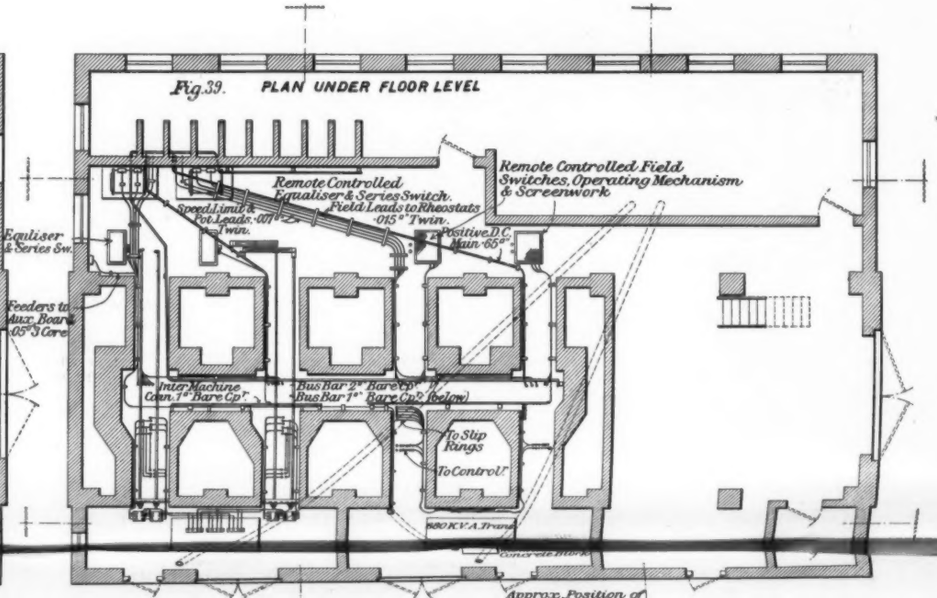

Remote Controlled Equaliser & Series Switch. Field Leads to Rheostats .015" Twin.
Remote Controlled Field Switches, Operating Mechanism & Screenwork
Speed Limit & Pot. Leads .007" Twin.
Positive D.C. Main .65"
Equaliser & Series Sw.
Feeders to Aux. Board .05" 3 Core
Inter Machine Conn. 1" Bare Cp.
Bus Bar 2" Bare Cp.
Bus Bar 1" Bare Cp. (below)
To Slip Rings
To Control
600 K.V.A. Trans.
Concrete Work
Approx. Position of

Fig. 40.

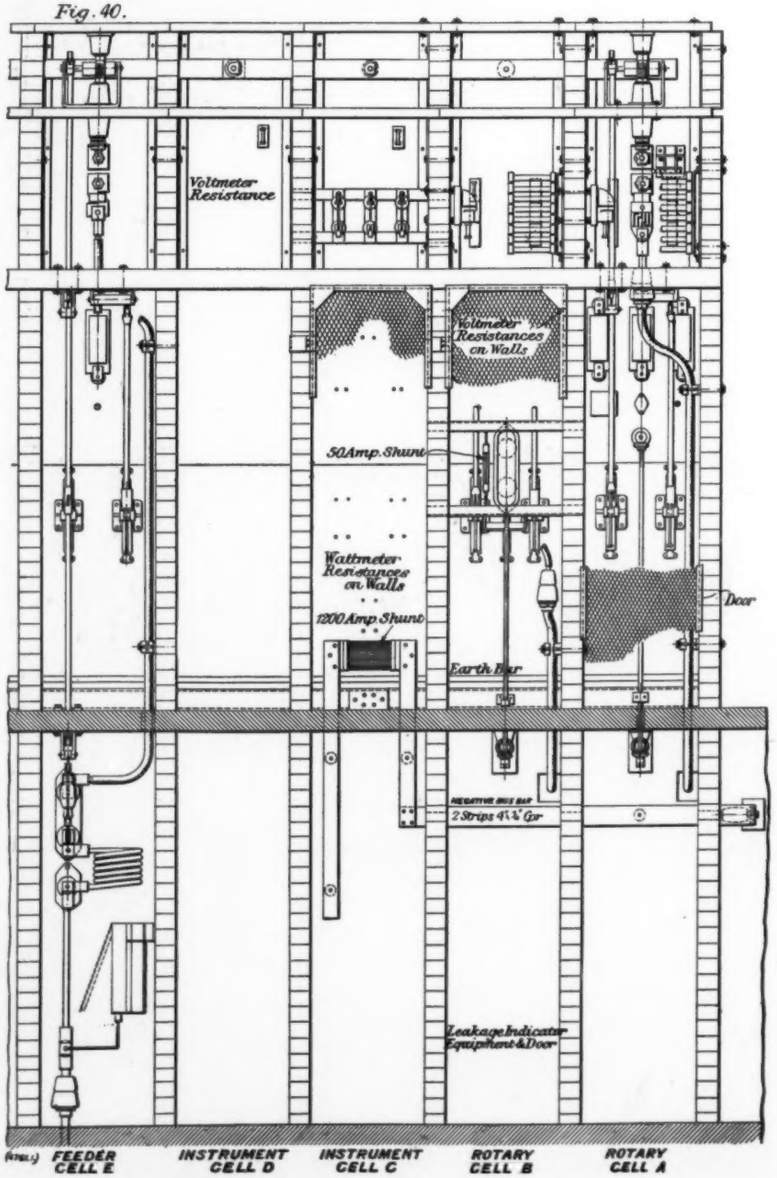


Fig. 41. ROTARY EQUIPMENT

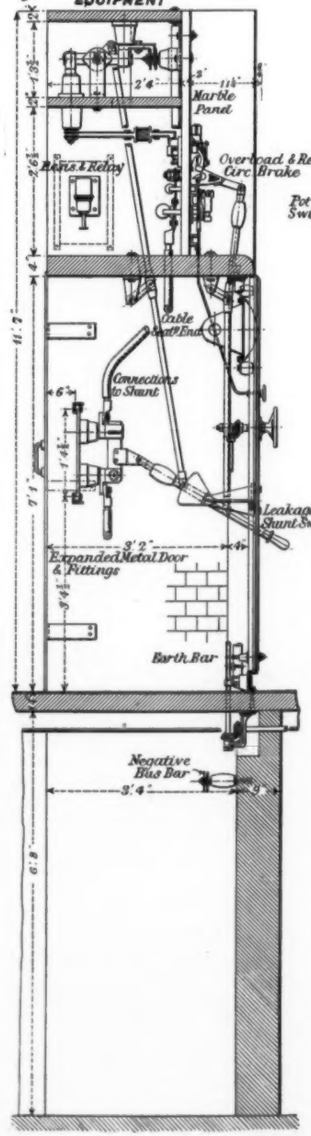


Fig. 42. INSTRUMENT PANEL

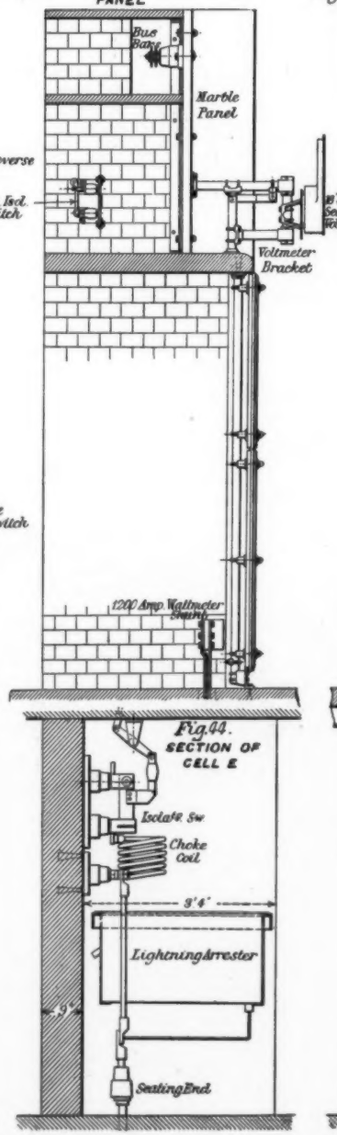


Fig. 43. FEEDER EQUIPMENT

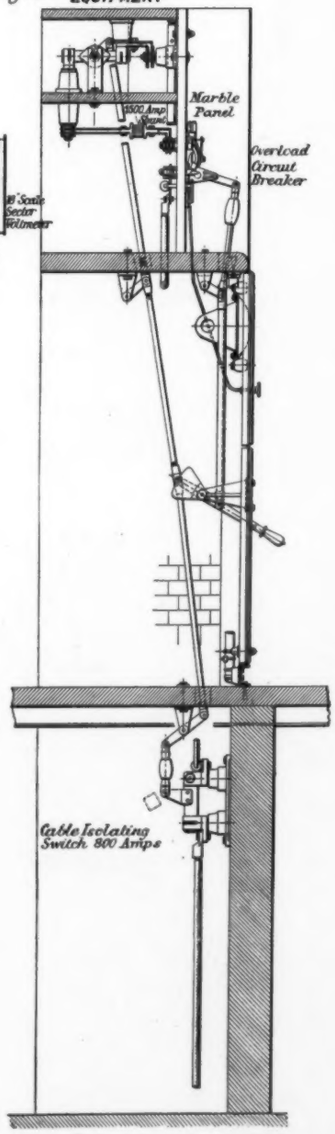


Fig. 44. SECTION OF CELL E

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Advertisements intended for insertion in the current week's issue must be delivered not later than 5 p.m. on Thursday. In consequence of the necessity for going to press early with a portion of the edition, alterations for standing advertisements should be received not later than 1 p.m. on Tuesday in each week.

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TELEPHONE NUMBERS—3663 and 8598 GERRARD.

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With a Two-Page Plate of the ELECTRIFICATION OF SHILDON-NEWPORT BRANCH, NORTH-EASTERN RAILWAY; SUB-STATIONS AT AYCLIFFE AND ERIMUS.

NOTICES OF MEETINGS.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.—Saturday, June 3, in the Wood Memorial Hall, Newcastle-upon-Tyne, at 2 p.m. The following papers will be open for discussion:—"Modern American Coal-Mining Methods, with Some Comparisons," by Mr. Samuel Dean. "The Hirsch Portable Electric Lamp," by Mr. Hiram H. Hirsch. "The Logic of Trams," by Mr. John Gibson. "The Influence of Incombustible Substances on Coal-Dust Explosions," by Mr. A. S. Blatchford, M.Sc. The following paper will be read or taken as read:—"Memoir of the Late George May," by Mr. Charles L. Dobson.

THE INSTITUTION OF RAILWAY SIGNAL ENGINEERS (INCORPORATED).—Tuesday, June 6, at 2.30 p.m., at the Institution of Electrical Engineers, Victoria Embankment, London, when a paper on "Faults on Telegraph and Telephone Circuits," by Mr. G. Edmondson, Assoc. Member, will be read and discussed.

THE RÖNTGEN SOCIETY.—Tuesday, June 6, at 8.15 p.m., at the Institution of Electrical Engineers, Victoria Embankment, W.C. The annual report of the Council will be followed by a paper by Professor J. W. Nicholson, M.A., D.Sc., on "Homogeneity of Visible Radiation," and an exhibition of X-Ray and Electrotherapeutic Apparatus. Demonstrations and short descriptions of new apparatus will be given by the exhibitors.

THE INSTITUTION OF GAS ENGINEERS.—Tuesday, June 6, the annual general meeting will be held at the Institution of Civil Engineers, Great George-street, Westminster. Morning: The chair will be taken at 10.30 a.m. Address by the President. Presentation of the Council's annual report, 1915-16, and statement of accounts for the year ended December 31, 1915. Report of the Refractory Materials Research Committee to be presented by the Chairman, Dr. H. G. Colman. Third report of the Ventilation Research Committee, to be introduced by the Chairman, Professor Arthur Smithells, and presented by Professor John Cobb, Livesey Professor. Supplementary report on "Thermal Phenomena in Carbonisation," by Professor Cobb and Mr. H. Hollings, Institution Gas Research Fellow, 1912-14. Afternoon: The chair will be taken at 3 p.m. Preliminary report of the Life of Gas-Meters Research Committee. Presentation of scrutineers' report. Nomination for election as honorary members: The President of the Société Technique de l'Industrie du Gaz en France, and Captain H. Riall Sankey, R.E. (ret.), M. Inst. C.E.

THE INSTITUTION OF MINING ENGINEERS.—Thursday, June 8, at 10.45 a.m., in the Rooms of the Geological Society, Burlington House, Piccadilly, London, W. 1. Professor F. W. Hardwick, M.A., will deliver a lecture, illustrated with lantern-slides, on "The History of the Safety Lamp." The lecture will be based on the paper entitled "Notes on the History of the Safety Lamp," by Mr. F. W. Hardwick, M.A., and Mr. L. T. O'Shea, M.Sc., which has been prepared for presentation at this meeting. The following papers will be read or taken as read:—2. "The Health of Old Colliers," by Mr. J. S. Haldane, M.D., F.R.S. 3. "The Estimation of Moisture in Coal," by Mr. T. F. Winmill, B.A., B.Sc. 4. "The Absorption of Oxygen by Coal," Parts VIII. and IX., by Mr. T. F. Winmill, B.A., B.Sc., 5. "The Oxidation of Pyrites," by Mr. T. F. Winmill, B.A., B.Sc. The following papers, which have already appeared in the Transactions, will be open for discussion:—(a) "Some Effects of Earth Movement on the Coal-Measures of the Sheffield District (South Yorkshire and the Neighbouring Parts of West Yorkshire, Derbyshire, and Nottinghamshire)," Part I., by Professor William George Fearnsides, M.A. (Cantab.), F.G.S. (b) "Compressed Air for Coal-Cutters," by Mr. Sam Mavor. (c) "Gas-Producers at Collieries for Obtaining Power and By-Products from Unsaleable Fuel," by Mr. Mansfeldt Henry Mills.

THE OPTICAL SOCIETY.—Thursday, June 8, at 8 p.m., at the Rooms of the Chemical Society, Burlington House, Piccadilly, W. The following paper will be read and discussed:—"Modern Technical Applications of Radium and other Luminous Substances" (with experiments), by Mr. F. Harrison Glew, M.R.I.

THE ROYAL INSTITUTION OF GREAT BRITAIN.—Friday, June 9, at 5.30 p.m. A discourse will be delivered by Dr. Ernest Clarke, M.D., F.R.C.S., M.R.I., Ophthalmic Surgeon to the King George Hospital, &c. The subject is "Eyesight and the War." Afternoon lectures next week at 3 o'clock. Tuesday, June 6. Mr. Thomas Martin Lowry, D.Sc., F.R.S., Lecturer on Chemistry, Guy's Hospital Medical School, on "Optical Research and Chemical Progress" (Lecture II.). On Thursday, June 8. Sir Alexander Mackenzie, Mus. Doc., D.C.L., LL.D., Principal of the Royal Academy of Music, on "Chamber Music and its Revival in England" (Musical Illustrations) (Lecture III.). Saturday, June 10. Professor Sir James G. Frazer, D.C.L., LL.D., D.Litt., Professor of Social Anthropology, Liverpool, on "Folklore in the Old Testament" (Lecture II.).

NOTICE TO NON-SUBSCRIBERS.

In view of the restrictions now imposed by the Government on the importation of paper, and of the consequent shortage of supplies, readers who wish to be sure of obtaining "ENGINEERING" each week should place an order for the Journal with a newsagent or bookstall clerk. Owing to the scarcity of paper it will be impossible in future fully to provide for a chance demand for this Journal.

ENGINEERING.

FRIDAY, JUNE 2, 1916.

MUNITION WORKERS.

ACCORDING to the French proverb, it is the first step that costs, and each of us has proved the truth of this by painful experience. The first day at school the first appearance in a works, and the first speech have each left a mark on the memory which will never quite fade. Yet in every case there were circumstances tending to mitigate the hesitation and confusion which naturally arose. The schoolboy and the apprentice cannot be accused of presumption in entering a new sphere. Each acts under the influence—or possibly the compulsion—of his parents, and the society into which he intrudes knows quite well that he would rather keep out. One would imagine that this would secure him a kinder reception than he usually gets; it certainly disarms any personal spite and only leaves him exposed to the practical jokes which are played by schoolboys and apprentices in common with other savages. The budding orator generally gets kinder treatment, for many even of the practised speakers among his audience have never quite escaped from stage-fright, and so have a fellow-feeling for his timidity. In none of these cases is the strain of the new start so serious as it is when an outsider endeavours to obtain a berth as a munition worker by offering himself, or herself, at the works gates absolutely without knowledge or experience of mechanical matters. The reasons which bring the applicant forward may be very various. He may act at the call of patriotism, or from love of change, or from mere desire for gain, but in no case can he hide from himself that he is volunteering to do something of which he is perfectly ignorant, and to do it in the presence of experts who resent his presumption. Little more than a year ago his offer would have been received with derision, and he would have been told that a five years' apprenticeship was a necessary preliminary. The changed conditions of to-day are evidence of the burden which has been laid on the manufacturing community of this country and under which many an antique theory has collapsed to the great surprise of those who had given unquestioning belief to it. The prospective munition worker is no longer repulsed at the gate, but is rather welcomed by the firm, if not by the foreman. A place is found for him, and what next befalls him is much a matter of chance. But whether he be put into hands which are sympathetic or antagonistic, for some little time he must cut a poor figure, due to the strangeness of his surroundings and his ignorance of mechanical matters. Thousands have faced this ordeal and have come successfully through it, but thousands more, no doubt, have quailed before it, and have missed the opportunity of "doing their bit" for the country.

All this is well known to the Ministry of Munitions, and in spite of the enormous responsibilities with which it is burdened, it has for many months past been playing the part of guide, philosopher and friend to many of those who were anxious to assist in manufacture. The point which it has taken up has been the provision of opportunities for the acquisition of elementary mechanical knowledge and aptitude on behalf of candidates in order that they might make their early mistakes among less critical surroundings than are found in an established works. On leaving its hands the potential munition worker has, at least, a superficial acquaintance with tools and machines, and generally a fairly complete knowledge of one operation in shell manufacture. He, or she, knows the names and purposes of ordinary tools and machines, and can be trusted to handle them without damaging either himself or the machines. To some extent the mechanical instinct, which is latent in most people, has been aroused, and stands ready to be cultivated in the more stimulating atmosphere of the munition works. Access to the works is further facilitated. Those who have passed through the training find themselves drafted into works where vacancies await them, and thus they are relieved from the embarrassing difficulty of applying at the gates for a position which they must acknowledge they cannot fill until they have been trained. In a word, the "cost" of the first step has been immensely cheapened, and the way of patriotic endeavour rendered easy to thousands of persons who would never have won through without such assistance.

The Ministry of Munitions makes no pretence of turning out skilled mechanics. All that it aims at is to render candidates capable of doing one job sufficiently satisfactorily to make them acceptable in a works. In doing this it is only carrying further the principle of specialisation, which is the prominent feature in all modern manufacturing operations. For a long time the sphere of each man's work has been steadily narrowing and the calls on his resource and originality dwindling until, under the Taylor system, the man became an automaton, who goes through a prescribed cycle in so many seconds and then begins afresh. The manufacture of munitions lends itself admirably to such a system,

for the orders often run into millions, and can be relied upon to be renewed again and again as long as the war lasts. It is not a difficult matter to learn to rough-turn the exterior of a shell to fit a gauge, or even to mill the thread in the nose, and something of this kind is all that is required of a munition worker. Indeed, it is most necessary that he should not imagine that he is a mechanic, for if he does he is pretty certain to afford a practical demonstration of the danger of a little knowledge.

Naturally, the Ministry of Munitions could not undertake the training of thousands of workers itself, and had to appeal for assistance to bodies who had plant and teachers available. They found a ready response in many districts, and already several thousands of munition workers have been turned out. In the Metropolis the London County Council arranged facilities at the Brixton School of Building, at the Shoreditch Technical Institute, at the Poplar School of Engineering, at the East London College, and at the Goldsmiths' College and elsewhere. In these institutions the instruction comprises a general course in bench work and machine-tool practice, and special courses in lead-burning, tool-setting, and gauge-making. Taking the School of Building as an example, there were there in July, 1915, 30 lathes and 11 drilling machine, besides other machine tools. With these a good deal of instruction in handicraft could be given, but very little of the specialised knowledge which is wanted in the munition worker. Other machines have since been obtained, including six capstan lathes, 12 milling machines, of which some are fitted for profiling, two turret lathes, &c. A further delivery of special tools is expected soon, and then it will be possible to ensure that each pupil has attained some degree of proficiency in at least one operation in shell-making.

Candidates for munition-making come from many walks of life, some of which seem very unlikely. A sweet girl graduate may be found working between a pert parlourmaid and a middle-aged matron, while a brieflees barrister may rub shoulders with a butler and an out-of-work architect. Their abilities are as various as their origins. Some have to be tactfully told that they had better seek some other sphere of usefulness. Some few give evidence that they should have been mechanics from the first. The more likely ones are sorted out to become tool-setters and gauge-makers. The former are in great demand, for the average munition worker is quite incapable of tool-setting, while the vast increase of capstan lathes, turret lathes, automatics and semi-automatics, has called for a great number of men capable of managing them. Of course, tool-setting is highly skilled work, and it is impossible to make a beginner into a capable mechanic of this kind within the few weeks that are available. But by carrying specialisation also into this department it is quite feasible to train a man to set the tools on one class of machine, doing one variety of operation, in a reasonable time; and that is what is being done with success, not only by the Ministry of Munitions, but also by private firms. We regret to learn that in some cases union workers are placing obstacles in the way of the introduction of this class of labour. Such action if persisted in will have effects that will be felt most severely in the trenches by the friends and companions of those who are promoting it. If there were skilled men available for this work the matter would not call for notice. But there are not. The output of some munition factories is already suffering from want of tool-setters. The machines are there, and the minders are there, but there are not sufficient tool-setters to keep them going at their best. The means for training setters are being rapidly perfected, and nothing should be allowed to hinder a process that will do much to speed up the output of munitions. It should be enough to point out that every week the war is prolonged thousands of lives are sacrificed and thirty millions sterling of the capital of the country is destroyed, and that labour must necessarily bear its share of the loss in some way or other.

We have not yet come to the end of the process of dilution of labour, and still more workers are required. To these the Ministry of Munitions extends an invitation. It puts at their disposal premises, plant and teachers, free of cost, and after a short period of pupilage they should be qualified for fair wages, which may grow, under conditions of piece-work, into a remuneration that would be tempting to many a young professional man upon whose education and training hundreds of pounds have been spent. In the past the methods and plant may have been somewhat inefficient, and some of the pupils may have failed to realise the limitations of their knowledge; but every day sees improvement in these respects, while the net result is that thousands of workers are now adding to our resources who would have stayed at home if the Ministry of Munitions had not taken them by the hand and encouraged them to take the first step.

THE IRON AND MANGANESE ORE DEPOSITS OF BRAZIL.

GERMANY, as has several times been pointed out, is keeping a very watchful eye on South America, including Brazil. Some two years ago, as stated by the *Frankfurter Zeitung*, a group of German financiers started a project for the acquisition of manganese and iron-ore deposits in Brazil with the intention of exporting the ore to Germany. This scheme, however, was frustrated by the Brazilian Government, which wanted to interest foreign capitalists in the exploitation of the mines and the ore within the country, so as to further Brazilian industry. The crisis, which the great war caused within the country, showed that this industry was anything but vigorous. It may therefore be surmised that the present Brazilian Government will view the question of export of iron ore more favourably than their predecessors. Actual prohibition against the export of iron ore does not exist. Both in the State of Bahia and in Minas Geraes ore is broken and the production mostly exported to Europe, to the west coast of England. During the year 1914, according to Brazilian statistics, 245,816 tons of high quality manganese ore were exported, representing in value 2,950,000 milreis (147,500*l.* now). The Companhia Manganez da Bahia exploits the manganese ore deposits situated within the district of Santo Antonio de Jesus and transports the ore by means of a narrow-gauge railway to the port of Nazareth, from whence it is shipped by sailing vessels to the large trans-oceanic steamers. The ore contains on an average 45 per cent. of manganese, 0.0016 per cent. phosphorus, 3–6 per cent. silicon, 3–4 per cent. iron and 2–3 per cent. moisture. The export duty is 11s. 6d. per ton, the freight to an English port averages some 10s. 6d. in normal times.

The existence of numerous other deposits of manganese and iron ore near the rivers or along the central railway has already been ascertained, but their exploitation has been hindered by the absence of a home iron industry and by the difficulties the State, so far, has put in the way of the export. There are in Brazil only two small blast-furnaces, worked with charcoal. The development of larger iron works has been impeded by the absence of suitable coal for blast furnaces within the country; lime of excellent quality is available in the immediate neighbourhood of the different ore deposits. The Brazilian iron industry will in any case for years be but a small consumer, and the State must therefore look for buyers of the surplus ore abroad.

An arrangement between the Brazilian interests, bent upon the establishment of an iron industry within the country, and German financiers desirous of importing Brazilian ore into Germany, might, however, be brought about if the latter agreed to reduce a part of the ore in Brazil. The ore deposits so far opened are partly held by the State and partly by private concerns. The Brazilian Government holds out prospects of import into the country, free of duty, of coal and the necessary plant, tariff protection for the production, State contracts, favourable freights and some other facilities. Of late years Germany has annually imported an average of about 250,000 tons of manganese ore, and her foreign requirements of this commodity have principally been supplied from Greece, Spain, Russia, Asia Minor and India. An increased import from Brazil, from whence small quantities are already being obtained, would have a favourable effect upon the price level of the manganese market. The valuable Brazilian hematite and magnetite, free from titanium and sulphur, can be placed at a reasonable price on the European market. The actual cost of production is very small, as the ore generally can be worked from the surface, and hand labour in the districts in question is cheap, about 2s. 8d. per day. The freights would probably be about the same to Rotterdam as to England. From Rotterdam to the Rhine–Ruhrort harbours there will be an additional 1s. or 1s. 6d. to pay. For the Bessemer and Siemens–Martin process there is probably no more appropriate material. As regard price, much hangs upon the manner in which the Brazilian State will facilitate the export. The Brazilian United States look upon export duties as their principal source of revenue. Owing to over-production the two main articles, coffee and rubber, have fallen considerably in price, and Brazilian industry is suffering severely in sympathy with this. The Government has realised that the country no longer can depend only upon two articles of production. There is, consequently, every reason to believe that Brazil will foster attempts intended to create a flourishing mining industry.

SOUND PROPAGATION AND ZONES OF SILENCE.

ON quiet evenings weak sounds are often carried to surprising distances. On the other hand, sailors not infrequently fail to pick up the sound of a fog-horn, which then suddenly bursts upon them, though they had been straining their hearing to catch the signal. Curious observations have been made as regards the distances to which the roar of explosions and of volcanic eruptions have been carried. In the case of a dynamite explosion occurring in 1903, at Förde, near Bochum, in Westphalia, the crash was heard close by and in an irregular area to the east, 100 km. and more distant, but hardly in other directions or in the intervening belt. When dynamite exploded on the Jungfrau Railway at Eigerwand in 1908, there were again two irregular areas in which the explosion was heard—one near the spot, the other far out. Here the mountains may have had a decided influence in reflecting the sound waves; but in the Asama eruption of 1914, in Japan, two zones of sound, one east, the other west of the volcano, were separated by a belt of silence nearly 100 km. in width. In most of these and similar cases no preparations could be made for observation, and the evidence is of doubtful value.

During the siege of Antwerp, in the beginning of October, 1914, Dr. van Everdingen, director of the Netherlands Meteorological Observatory at Utrecht, was informed that the guns were heard at some places, but not heard at intervening spots, and he asked the meteorological observers at the various stations of the kingdom to pay attention to these phenomena. The result was that in the days October 7 to 9 and later, after the fall of Antwerp, during the battles near Ypres and off the Belgian coast, a great many observations were collected at distances up to 200 and 300 km. from the engagements. The reports, which Dr. van Everdingen discussed in the Proceedings of the Amsterdam Academy and also in the *Revue Générale des Sciences* of April 30, 1916, were not in the best agreement, of course. But it seems to be established that there was, apart from local zones of silence, on various days a zone of relative or complete silence inside the radius of 160 km.; this zone of silence had a width of about 50 km.; beyond the distance of 160 km. the sound became weakly audible again, decreasing in intensity with increasing distance. At some of the stations far out the sound did not appear to come from the south-west, the true direction.

Attempts have at various times been made to account for the phenomena on meteorological lines, somewhat after the manner of the mirage problem. As a rule the temperature of the air falls as we ascend from the earth; the velocity of sound therefore decreases upward, and a ray of sound, so to speak, which was nearly horizontal to start with, would curve more and more upward by re-

fraction; this refraction of sound waves is greater than with light waves. On the other hand, there is, in the case of sound, no total reflection, which plays so important a part in mirage. When the air becomes first warmer in the lower strata, the velocity of sound increases, and rays of sound are curved downward. The wind, especially if across the line of sound propagation, makes little difference. But the wind is of importance in another respect. The wind frequently becomes stronger in the upper strata, and, moreover, changes gradually in direction. The upper atmosphere absorbs much less of the energy of the sound waves than the surface air. The general effect of an increased wind velocity in the upper atmosphere will be that of increased refraction—that is to say, the sound will travel to a greater distance in a curved path than in a straight direction; and if there be a change in the wind direction at a certain height, zones of silence will be created, especially if the air be violently disturbed and locally heated by explosions or the hot gases from volcanoes. Explanations on these lines have been proposed by Mohn, Rayleigh, Fujiwara, and others.

This explanation, though probably correct in most cases, does not well admit of quantitative treatment, and Dr. van Everdingen prefers, in his case, the "physical" explanation of von dem Borne (*Physikalische Zeitschrift*," 1910, page 483) to the meteorological, because the meteorological conditions over Holland and the Continent on the days in question were unfavourable to the former. According to the physical view the different gases in the atmosphere have each their own velocity of sound. There is hydrogen in the atmosphere; its percentage is very small on the surface (0.01 per cent.), but increases with height. Borne even suggests the figure of 98.6 per cent. at a height of 100 km. This, of course, is entirely hypothetical; in fact, the suggestion has partly been made to account for phenomena otherwise difficult to explain. As the height increases, the velocity of sound in the hydrogen-air mixture will increase, until finally the curve will turn towards the surface again, which it should strike at a distance of 114 km. from its source, according to Borne. Now Everdingen observed his recurrence of sound perception beyond a zone of silence at 160 km. The two figures, therefore, do not agree; but the percentage of hydrogen in the surface air is at present assumed to be only 0.00055 per cent. (G. Claude's estimate), and accepting that percentage for his deductions, Everdingen finds his figure 160 km. confirmed. The weather conditions would influence this consideration very slightly; for weather changes are confined to the 10 or 12 km. of the atmosphere next the earth, but do not extend beyond the so-called isothermal layer found at that altitude in our latitude, whilst the bend of the curve can hardly occur at an altitude of less than 100 km. It may be objected that the acoustic energy of waves coming from that height would be too feeble to affect the ear; but the ear is very sensitive, and as a matter of fact the sounds perceived were weak. The theory might be checked in one way. If the acoustic waves travel first up into the air and then down again, covering perhaps twice the direct distance from the source, they should be heard later than with straight-line propagation. In the case of the Asama eruption there was some evidence to that effect; but the observations were uncertain. The question is not without importance, and experiments might be made during the war. Propagation of the sound waves through the earth, to which Dr. van Everdingen hardly alludes, would have to be considered; in that respect a difference between naval bombardments and land bombardments should be observed.

NOTES.

The Strength of Flat Plates.

In a paper recently published in the *Revue Générale des Sciences*, M. Zack gives some formulæ for the stresses on flat rectangular plates uniformly loaded with p lb. per sq. in. He states that if the plate be *encastré* the maximum stress occurs at the middle of the long sides, the stress at the centre of the plate being not half as great. If a denote a short side and b a long side of the plate, then if the ratio $\frac{a}{b}$ is greater than one-third, the bending moment at the middle of the long side, b, is equal to $\frac{p\,a^2}{12}$. If, on the other hand, $\frac{a}{b}$ is less than one-third, then the bending moment at the middle of a long side is equal to $k_a \frac{p\,a^2}{12}$ where the value of k_a is as follows:—

$\frac{b}{a}$	2.5	2	1.8	1.6	1.4	1.2	1.1
Value of k_a is	0.99	0.96	0.94	0.91	0.86	0.79	0.64

In the case of the short side, taking the plate *encastré* as before, the bending moment at the mid-point is equal to $k_b \frac{p\,b^2}{12}$. Where k_b has the following values:—

$\frac{b}{a}$	2.5	2	1.8	1.6	1.4	1.2	1.1
Value of k_b	0.03	0.06	0.09	0.14	0.22	0.38	0.64

At the corners of the plate the sign of the bending moment is reversed.

Jerry-Building 100 Years Ago.

In a paper read before the Concrete Institute, Mr. W. G. Perkins observes that the popular idea that buildings in the "good old times" were solidly constructed is erroneous. The majority of the buildings erected in London 100 to 200 years ago were, he states, constructed in the most inferior way. The mortar appears to have been compounded with a fat lime, dry slaked, mixed with the "top spit" of the field. Naturally it has had no binding properties, and is now just so much dusty rubbish. The bricks, moreover, were badly shaped, and they were easily broken, so that in taking down old walls course after course of what appear to be headers are found to be merely "bats." The wall thus consists of a number of 4½-in. layers with no efficient interconnection. These have separated and bulged, this condition being the state of many dangerous structures to-day. This bulging is, Mr. Perkins states, generally found in the basement storey, where the thickness of the wall is suddenly diminished by a set-off from, say, 1 ft. 10½ in. to 1 ft. 8 in. In other cases a triangular patch of brickwork bursts from the walls. He has, moreover, observed a number of cases in which party walls 50 ft. high and perhaps 200 years old have failed by crushing, though subject to little more than their own weight, the stress being certainly under 3 tons per sq. ft. Brickwork of this inferior quality is, Mr. Perkins states, always stronger when exposed to damp, as the moisture enables the mortar to set to some extent. In other cases old walls have been found to consist of two skins of brickwork 4½ in. thick, tied together by wooden laths at 18-in. intervals, the space between being filled in with small pieces of brick and stone. Many variants of this procedure were frequent, it appears, in the building practice of our ancestors.

Grain-Size Measurements in Metals.

According to the amorphous cement theory all metals and alloys in the solid state are mixtures of the crystalline and amorphous phases of the metal or components, and it is believed that the finer the grain the greater will be the proportion of the amorphous phase. The exact correlation between grain-size and physical properties is not clear. But the interpretation of the customary mechanical tests to which metals are submitted is likewise controversial, and grain-size measurements offer the advantage over other tests that they do not require elaborate preparation of the test specimen, and that they are made on the metal in the state in which it is to be used. That fine grain and high tensile strength and elastic limit go together is generally conceded. The subject was brought before the Faraday Society in a paper on "Grain-Size Measurements in Metals and the Importance of such Information," which Mr. Zay Jeffries, of Cleveland, Ohio, contributed to the discussion on "Solid Solutions and Annealing."* As a good example of increase of hardness with decreasing size of grain, Mr. Jeffries quoted some quite recent experiments of Fahrenwald, who prepared puré gold in four degrees of grain size, the extremely fine grain being secured by starting from colloidal gold; the hardness ranged from 94.7 down to 23.8, in Brinell numbers. Grain-size measurements can be made, generally on a polished and etched section, in various ways; if the number of grains per square unit be n, there will be $n^{\frac{3}{2}}$ grains per cubic unit. The planimeter method projects an image of the polished section on to a piece of paper, counts the single grains, traces their boundaries and determines the total area, which may be quite irregular. In the intercept method a diameter is drawn across the circular field of view of the microscope, the grains cut by the line are counted, and the measurements are repeated on different diameters. Heyn's method, to which Mr. Jeffries particularly referred, measures the intercepts in two diameters at right angles to one another. The comparison method (applied by Grard chiefly to annealed brasses) prepares a set of samples of known conditions and takes micrographs of them; phosphorus and carbon in iron can be controlled by this very flexible method, without actual grain-size determination. Mr. Jeffries himself counts the number of grains within a circle which should be well within the field. Supposing the circle encloses 66 complete grains and cuts 28 grains, which partly lie outside the circle; then he finds that $66 + 28 \times 0.6 = 82.8$ grains is a fair average. The factor 0.6 was the mean of a great many determinations made on circles enclosing from 20 up to 290 complete grains; the factor actually varied from 0.54 to 0.62, and if the boundary grain estimate should be wrong by 5 per cent., the total grain number would be wrong by 1 per cent. only, whilst the intercept and Heyn methods gave much larger errors. He generally takes a circle of 79.8 mm. diameter and gave, in his paper, a table, by the aid of which the number of grains per square millimetre could be read off for magnifications from 25 to 2000 diameters. Measurements are made with a camera-microscope on screens (ground-glass or paper) or photographs, the circle being drawn on a piece of tissue paper, attached to the screen; the circle should not enclose less than 50 grains. Some conclusions, it was said, could be drawn as to the cold work the metal has undergone, as stretching and compression would affect one direction in particular, Heyn's method was recommended for this comparison. But thermal expansion by annealing complicated this interpretation, and grains and cells should be distinguished. Sir Robert Hadfield mentioned in this connection that he had counted, in a 0.58 carbon steel, the following number of grains per square inch: 5540 as forged, 4500 annealed, and 330,000 water-quenched; with very fine grains, however, the microscopic determination became almost impossible.

* See page 454 *ante*.

The Institution of Heating and Ventilating Engineers.—At a special council meeting held on the 23rd ult. it was decided not to hold a summer meeting this year.

United States Steel Corporation.—At the close of April the unexecuted orders of the United States Steel Corporation represented a record aggregate of 9,829,551 tons. This is an increase of 498,550 tons as compared with the unfilled orders at the close of March. At the close of April, 1915, the "unfilled" total was 4,162,244 tons; at the close of April, 1914, 4,277,068 tons; and at the close of April 1913, 4,978,762 tons. The monthly totals of the unexecuted orders of the Corporation during the six months ended April 30 this year were as follow:—November, 1915, 7,899,899 tons; December, 1915, 7,806,220 tons; January, 1916, 7,922,767 tons; February, 1916, 8,568,966 tons; March, 1916, 9,331,091 tons; and April, 1916, 9,829,551 tons.

The United States Aeroplane Industry.—We read in the *Iron Age* that the remarkable growth of the aeroplane industry of the United States is indicated by the exports of 398 aeroplanes for 1915, against 40 in 1914 and 19 in 1913. The value of the 1915 exports was 2,960,814 dols., or an average of 7439 dols. per machine, against the 6337 dols. in 1914 and 3227 dols. in 1913. The exports of aeroplane parts were also very large, amounting to 2,457,782 dols., as compared with only 145,997 dols. in 1914 and 25,606 dols. in 1913. Imports of aeroplanes into the United States decreased from 16 and 13 in the fiscal years of 1912 and 1913 to only one each in the fiscal years of 1914 and 1915.

LITERATURE.

A Treatise on Safety Engineering as applied to Scaffolds. The Travellers' Insurance Company, Hartford, Connecticut. [Price 3 dols.]

THE writer of this book, who remains anonymous, but is apparently an expert connected with the Travellers' Insurance Company, of Hartford, U.S.A., occupies himself solely with the arrangement and details of scaffolds and their accessories. The principles of scaffold construction as a whole, considered from an engineering point of view, are not discussed, and the theoretical rules of applied mechanics determining the strength and stability of such structures are also left on one side. The safety of the workman is the main topic, and a sufficient; every safeguard that tends to reduce risk is cogently and properly insisted upon. Very sympathetic attention will be given to the many hints and suggestions that are made with the view of securing greater safety, for all builders are anxious to adopt precautions that will diminish casualties. Nothing is said of the legal enactments or of the employers' liability in the States. This is important, and it would have been of interest to know to what extent the precautionary measures recommended are voluntary or compulsory. From the fact that statistics of accidents are imperfect, and are not methodically collected by a State Department *ad hoc*, we gather that inspection is lax, and that public opinion needs to be educated. From newspaper reports and similar sources, the author shows that on an average one accident happens per diem in the United States. Such an estimate must be a minimum, and but little reliance can be placed on such a compilation. The collection is more instructive as showing the character of the injuries, and the percentage that is attributable to defective construction. In 40 per cent. of the quoted instances men fell from a scaffold, while the structure remained undisturbed; and it is a fair inference that the majority of these casualties might have been prevented if due precautionary measures had been insisted upon in the general arrangement. In about 33 per cent. of the reported cases the injury proved fatal, and in the far greater number of accidents the injury was confined to a single workman. These incomplete statistics are sufficient to show the need for closer inquiry, and justify the author in urging the adoption of improved safeguards whose introduction would doubtless ultimately prove economical.

The subject of scaffolding has been rather neglected in the standard treatises on building, but its importance is likely to come into greater prominence as the lofty buildings now being erected in the United States and elsewhere demand facilities that will expedite construction, afford safety at great heights, and prove economical in use. Pole scaffolding that becomes less efficient and more expensive with height does not fulfil these requirements. Lofty buildings crowded with occupants have many and evident disadvantages, but they are likely to come more and more in demand where land is valuable and the extent of accommodation restricted. In their favour it is urged that such structures offer the only means for facilitating ready intercourse among the officials of large corporations, and for securing an adequate return on the investment. On the other hand, there is no interest on the capital while these large structures are going up, and time is grudged for the erection of scaffolding, which must be substantial and massive if it is not to collapse under its own weight. Mammoth erections of fifty-five stories, with towers approaching the 800-ft. level, have already made their appearance, and to ensure the requisite rapidity of erection new methods of building have been introduced. One outcome of this policy for hustle has been the steel-framed building in which the weight of the walls is carried at each floor level by the steel frame. Such a form of construction has rendered possible the suspended scaffold now in general use wherever the building exceeds five stories in height and the steel framework is available. It is usual in such structures to carry the steelwork to a considerable height before bricklaying begins, the steelwork providing efficient support for a platform swung on steel cables from the highest level, and provided with suitable mechanism for altering the height of the platform as the work proceeds. Such a plan has several advantages besides economy; it permits of work being prosecuted at different heights simultaneously, one platform being, if necessary, vertically over another, protection from wind is more readily provided, the system possesses great flexibility, is capable of ready adjustment to the height convenient for the workmen, and steel cables take up less room than pole scaffolding. But the working of the platforms and the management of the mechanical gearing become a little complicated, and the effective handling requires a different training from that of the ordinary mason, or scaffold-man. Indeed, the necessities of the trade have called into existence a special class of platform-scaffold builders, who lease out the necessary mechanism under the care of trained experts.

The description of these platforms and of their working is the most distinctive feature in the book, and much of the information is welcome, clearly expressed, and the explanation assisted by appropriate illustration. But the details are carried to rather a wearisome extent, and, indeed, the whole book would have gained in force and interest by judicious condensation. Much is made of two different types of scaffolding in use, but there is no mechanical or generic difference between the two. In one case, called the "overhead" form, the winding-drums and the attached cables are placed high overhead at the point where the suspension-ropes are secured to the steel frame of the building. In the alternative case, the drums are placed on the platform itself, and consequently move with it. The point to be kept in view is the possibility of altering the lengths of the suspension-ropes so as to fix the working platform in the most convenient position. The object of the book is to insist on the safeguarding of the workman, and this purpose may be obscured if minute details of construction are discussed. For this reason it seems a little injudicious to regard as separate structures requiring distinct treatment the ordinary bricklayer's pole-scaffold, in which the wall itself is used for supporting the inner edge of the working platform, and the self-sustaining form of two parallel rows of poles. Similarly, the bracket scaffold is a special form of the "outrigger" pattern, and other examples of repetition might be quoted. However important it may be to insist on certain precautions in attachment in slightly different combinations, we should never be allowed to lose sight of the main purpose of the book—the necessity of a margin of safety. The employment of suitable materials ensuring strength and stability of the whole structure, the provision of guard-rails, foot-boards, protecting-screens for workpeople and the public are insisted upon urgently, and with such force as to suggest that in America personal safety is regarded as of small importance.

A feature of interest for the English reader is the comparison of the practice pursued in the States with that followed in this country. The round form of pole usually employed here in a bricklayer's scaffold is not approved. The uprights are usually shorter than with us, and are sawn to rectangular form, the better to admit of nailing. The use of the scaffold-rope is discouraged. So little are ropes used that many scaffold-builders have forgotten how to tie a rope so as to make it effective. Regarded superficially, it would seem that considerable damage to the timber is likely to follow from the use of heavy nails, especially when the scaffold is dismantled, shortening the life of the poles. The increasing price of timber of a kind suitable might compel builders to take the lashed scaffold into favour again; but, on the other hand, it is urged that the saving of time and labour by the use of nails is a sufficient compensation. When a scaffold is lashed with rope, the full time of two men is required, with occasional help from a third; but by using nails a bricklayer's pole-scaffold can be erected by one man, with help from a second in getting the uprights into position. In England the putlogs are usually split, and not sawn, and such plan seems desirable in order to avoid cutting the fibres; but the Americans prefer sawn timber, and, moreover, the putlogs are not lashed to the ledgers, as is usual here, but simply rest on the ledgers, being kept in position by their own weight. The author defends the practice, and doubtless those measures are to be recommended that have the sanction of long usage. The author has rendered a service by pointing out how risks may be reduced without introducing any violent innovation.

BOOKS RECEIVED.

Graphics and Structural Design. By H. D. HESS, M.E. Second Edition. New York: John Wiley and Sons (Inc.); London: Chapman and Hall, Limited. [Price 12s. 6d. net.]

Sulphuric Acid and Sulphur Products. By GEOFFREY MARTIN, D.Sc., &c., and Major J. LOUIS FOUCAR, B.Sc. London: Crosby Lockwood and Son. [Price 7s. 6d. net.]

The Flying-Machine. Two Papers: the Aerofoil and the Screw-Propeller. By F. W. LANCHESTER. London: Institution of Automobile Engineers, 28, Victoria-street, S.W. [Price 3s. 6d. net.]

An Elementary Manual of Radiotelegraphy and Radiotelephony for Students and Operators. By J. A. FLEMING, M.A., &c. Third Edition. London, New York, Bombay, Calcutta and Madras: Longmans, Green and Co. [Price 7s. 6d. net.]

Modern Workshop Practice: A Manual for the Use of Engineers, Apprentices and Students in Technical Institutes. By ERNEST PULL. Second Edition, revised and enlarged. London: Crosby Lockwood and Son. [Price 5s. net.]

The Ruling Caste and Frenzied Trade in Germany. By MAURICE MILLIOUD. With an Introduction by the Right Hon. Sir FREDERICK POLLOCK, Bart. London: Constable and Co., Limited. [Price 4s. 6d. net.]

Screw-Cutting for Engineers: A Hand-Book for Practical Mechanics and Technical Students. By ERNEST PULL. Second Edition. London: Crosby Lockwood and Son. [Price 1s. 6d. net.]

The Two-Stroke Engine: A Manual of the Coming Form of Internal-Combustion Engine. By Dr. A. M. LOW. London: The Temple Press, Limited, 7-15, Rosebery-avenue, E.C. [Price 1s. 6d. net; post-free 1s. 9d.]

The Civil Engineers' Cost-Book: Compiled for the Use of Civil and Municipal Engineers, Public Works Contractors, &c. By Lieut.-Colonel T. E. COLEMAN. Second Edition, revised and enlarged. London: E. and F. N. Spon; New York: Spon and Chamberlain. [Price 6s. net.]

Western Australia: Geological Surveys. Bulletin No. 58. *Palæontological Contributions to the Geology of Western Australia.* Series V., No. X. By R. ETHERIDGE, Junr. No. 62. *Notes on the Geology and Mining at Sandstone and Hancock's East Murchison Goldfield.* By E. DE C. CLARKE. *Petrology.* By R. A. FARQUHARSON. No. 65. *The Reputed Petroliferous Area of the Warren River District (South West Division).* By H. P. WOODWARD. With *A Contribution on Asphaltum from the Southern Coast of Australia*, by E. S. SIMPSON, B.E., &c.; and *A Petrological Contribution*, by R. A. FARQUHARSON, M.A., &c. Perth, Western Australia: Fred. W. Simpson, Government Printer.

Trench Warfare. By Major A. R. RICHARDSON. London: The Westminster Press, 11, Henrietta-street, W.C. [Price 4d. net.]

The Metallography and Heat Treatment of Iron and Steel. By ALBERT SAUVEUR. Second Edition. Cambridge, Mass., U.S.A.: Sauveur and Roylston. [Price 6 dols.]

A Study of Industrial Fluctuation. By DENIS HOLME ROBERTSON, M.A. London: P. S. King and Son, Limited. [Price 7s. 6d. net.]

Forging of Iron and Steel. By WILLIAM ALLYN RICHARDS. London: Constable and Co., Limited. [Price 6s. 6d. net.]

American Sewerage Practice. Vol. III.: *Disposal of Sewage.* By LEONARD METCALF and HARRISON P. EDDY. New York and London: McGraw-Hill Book Company, Inc. [Price 25s. net.]

Autogenous Welding and Cutting. By THEODORE KAUTNI, Ing. Translated by the author and JAMES F. WHITEFORD. New York and London: McGraw-Hill Book Company, Inc. [Price 4s. 2d. net.]

The Marine Steam-Turbine: A Practical Description of the Parsons and Curtis Marine Steam-Turbines as Presently Constructed, Fitted, and Run: A Manual of Marine Steam-Turbine Practice. By J. W. M. SOTHERN. Fourth Edition, re-written up to date and greatly enlarged. London: Crosby Lockwood and Son. [Price 18s. net.]

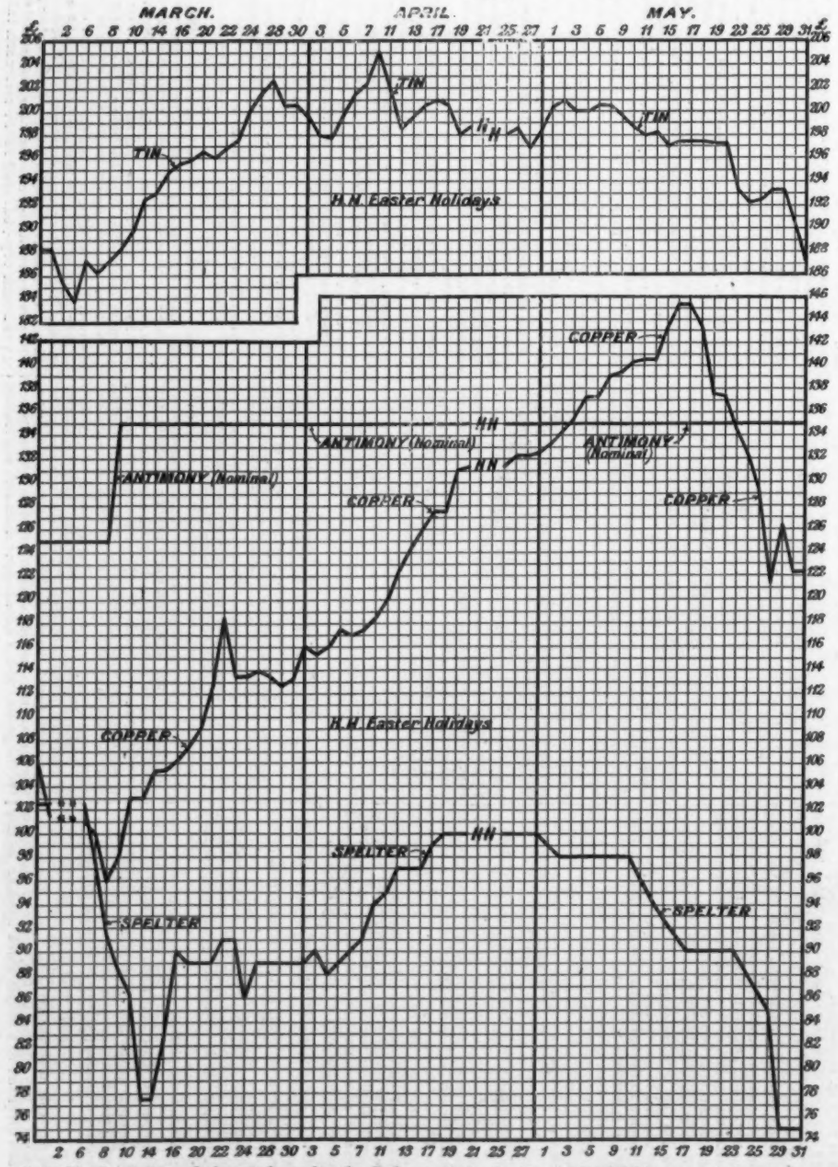
The Salt and Alkali Industry, including Potassium Salts and the Stassfurt Industry. By GEOFFREY MARTIN, D.Sc., STANLEY SMITH, M.Sc., and F. MILSON, B.Sc. London: Crosby Lockwood and Son. [Price 7s. 6d. net.]

Atti del Collegio degli Ingegneri Navali e Meccanici in Italia per l'anno 1914. Prima Parte. Genova: Tipografia di Angelo Cimmago. Vico Mele 7, interno 6.

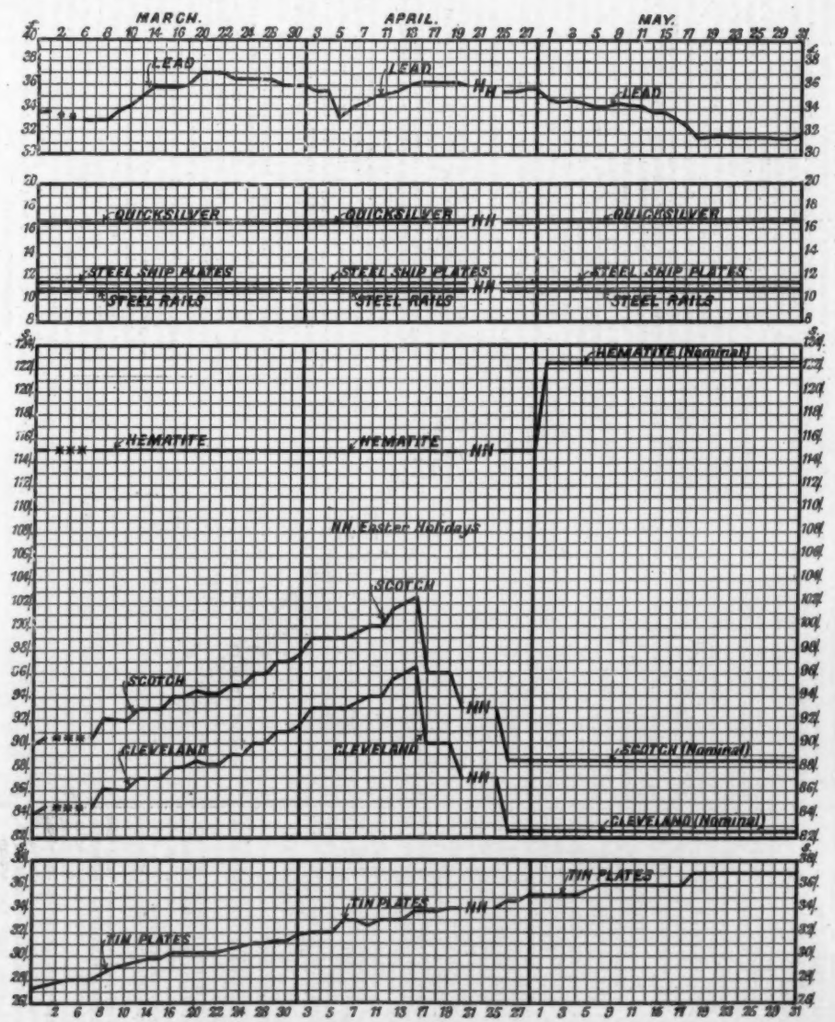
COAL IN ICELAND.—A syndicate has been formed in Copenhagen for the rational examination of some deposits found in a mountain in West Iceland, at Brede Bay, south of Patrick Firth. Samples have been pronounced to be coal by a Swedish expert, but the Danish authority, Dr. Hartz, maintains that they cannot be coal, but must be lignite. Coal dates from a period in the history of the world much older than any formation found in Iceland. Lignite is an outcome of the Tertiary period, older than which there is no formation in Iceland.

DIAGRAMS OF THREE MONTHS' FLUCTUATIONS IN PRICES OF METALS.

(Specially Compiled from Official Reports of London Metal and Scotch Pig-Iron Warrant Markets.)



* On March 1 last an Order made under the Defence of the Realm Act prohibiting speculative dealings in copper, antimony, spelter, lead, iron, and other metals required for war work, was published in the *London Gazette*. In consequence of this order business in these metals was suspended on the London Metal Exchange, and also on the Glasgow Pig-Iron Warrant Market, on the following day. The order, however, was not intended to restrict legitimate trading, and business of this kind was therefore resumed in London on March 6 and in Glasgow on March 7. At the close of the Glasgow Iron Market on the 31st May a notice was posted up stating that "owing to the action of the Minister of Munitions, the Glasgow Pig-Iron Warrant Market is suspended till further notice."



NOTE.—In the diagrams, on the present page the figures plotted for tin and copper are the official closing cash quotations of the London Metal Exchange for "fine foreign" and "standard" metal respectively. The prices plotted for antimony and lead are for English metal in both cases, while those for spelter are for American metal—the only kind at present available. Steel ship-plates and heavy steel rails are plotted to Middlesbrough quotations; the usual discounts are allowed in the case of ship-plates, but rails are net, free on board, at Middlesbrough. The figures plotted for hematite, Scotch, and Cleveland irons are Glasgow settlement prices, and these prices are per ton, as are also those for all other metals previously mentioned. The price of quicksilver is, however, per bottle, the contents of which weigh about 80 lb., and the price of tin-plates is per box of I.C. cokes free on board at Welsh ports. Each vertical line in the diagram represents a market day, and the horizontal lines represent 1*l.* each in all cases, except those of hematite, Scotch and Cleveland irons and tin-plates, where they represent 1*s.* each.

LABOUR EXCHANGES AND TECHNICAL STAFF APPOINTMENTS.

To the Editor of Engineering.

Sir,—I have read with interest the opinions of your several correspondents on the present Government system of controlling the movements of technically qualified engineers in this country. The case of a man whose qualifications were practically wasted through this Act was cited, while the work of the great retarding element, the Labour Exchange, together with the result of evading it, have been illustrated. To show how such a system assists the unscrupulous employer might also interest your readers.

Some few months ago a firm of great standing, having become somewhat "slack" in the office, approached some of their younger draughtsmen with a view of discovering their attitude towards taking up practical work in the shops, at the wage prevailing in the district. Those who recognised the move of the firm, and were prepared to take the risks entailed, objected, and were forthwith dismissed, while the others, being in a more dependent position, had to submit. The official responsible for the move knew full well that business would not always be "slack," and that to "store" draughtsmen in the shops was the cheapest and surest way of keeping them until he next required them, while the men who were qualified for better posts, besides having lost prestige, were unable to avail themselves of any opportunity to return to office work outside that of their employer, being, of course, engaged upon munition work.

The firm is busy again and the official prides himself on being able to lay hands on draughtsmen during the present dearth. To me it seems that the only way of mending such matters is to organise ourselves to combat it and approach those responsible for its administration.

Yours truly,

May 29, 1916. Technical.

"ON THE WHIRLING SPEEDS OF LOADED SHAFTS."

To the Editor of Engineering.

Sir,—I should feel obliged if you would allow me to contribute to the discussion in your journal on the vibrations of a shaft carrying a rotating disc.

In order to simplify the problem we may make the following assumptions :—

1. The trajectories of the different points of the disc are planes and are parallel to the plane of the Fig. below.

2. The angular velocity of the disc is constant and equal to ω.

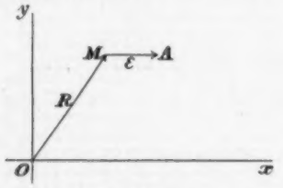
3. The plane of the disc is the plane parallel to the plane of the Fig. and passing through the centre of gravity M of the disc. This plane intersects at O the axis of the shaft considered at rest and free from the action of gravity. On the other hand, when the disc is in motion and submitted to the action of gravity, the axis intersects the plane of the Fig. at point A.

We may suppose that the elastic force which solicits the disc is proportionate to the distance OA and is in the direction of AO.

On the basis of these hypotheses, let m be the total mass of the disc; let us consider the vectors $\overline{OM} = \overline{R}$ and $\overline{MA} = \overline{\epsilon}$, placing a — above all the vectorial quantities.

Let us refer the motion to two axes $o\,x$ and $o\,y$ revolving in the same direction as the disc, positively.

If $o\,x$ be selected parallel to MA, as $\overline{MA}$ revolves in the same direction and with the same speed as $o\,x$, $\overline{MA}$ will always be parallel to $o\,x$, and as the distance ϵ from the centre of gravity to the axis of the disc is constant, then the vector ϵ is a constant.



Let us take as our origin, for time, the moment when gravity $m\,g$ is in the direction of $o\,x$; then gravity which is fixed in space revolves negatively when taken relatively to our axes of co-ordinates with speed ω, which means that its vector is represented by the circular function

$$m g\, e^{-i\omega t},$$

where t is the time.

The problem resolves itself in the investigation of the vector R = OM.

It is known that the relative motion of M when referred to the revolving axes $o\,x$ and $o\,y$ may be considered as an absolute motion on the condition of adding to the outside forces :—

1. The inertia force $m\,\omega^2\,\overline{R}$.

2. The component centrifugal force $-2\,i\,m\,\omega\,\dfrac{d\,\overline{R}}{d\,t}$.

Besides gravity, which acts upon the disc, we have as external force the elastic reaction of the shaft.

From our third assumption this is a vector equal to

$$-E(\overline{R} + \overline{\epsilon})$$

E being a modulus of elasticity.

This vector is not applied to the centre of gravity of the disc and gives rise to a couple which tends to modify the angular velocity ω, but on the basis of our second assumption we shall neglect the effect of this couple.

In these conditions, the resultant of the forces which solicit the disc, or

$$m\,\frac{d^2\,\overline{R}}{d\,t^2}$$

is equal to the geometric sum of all the forces enumerated above.

In writing down this vectorial equality, by uniting all the terms which contain $\overline{R}$ or its derivates in the first member, by dividing by m and using, as has already been done in your journal, $\dfrac{E}{m} = \omega_k^2$, we obtain the following differential equation :—

$$\frac{d^2\,\overline{R}}{d\,t^2} + 2\,i\,\omega\,\frac{d\,\overline{R}}{d\,t} + R\left(\omega_k^2 - \omega^2\right) = g\,e^{-i\,\omega\,t} - \omega_k^2\,\epsilon$$

This is a classical equation, the general solution of which is equal to the general solution of the equation without second member, plus a particular solution of the equation with second member.

The solution of the equation without second member has the form

$$\overline{R} = a_1\,e^{\,i\,(a_1\,t\,+\,\phi_1)} + a_2\,e^{\,i\,(a_2\,t\,+\,\phi_2)}$$

a_1, a_2, ϕ_1, ϕ_2, being the four integration constants of a vectorial equation of the second order, a_1 and a_2 being the roots of the equation of the second degree :—

$$a^2 + 2\,a\,\omega - (\omega_k^2 - \omega^2)$$

$$\text{or } a_1 = -\omega + \omega_k \text{ and } a_2 = -\omega - \omega_k$$

A particular solution of the equation with second member is :—

$$\overline{R} = \frac{g}{\omega_k^2}\,e^{-i\,\omega\,t} - \frac{\omega_k^2}{\omega_k^2 - \omega^2}\,\epsilon$$

The general solution is therefore :—

$$\overline{R} = \frac{g}{\omega_k^2}\,e^{-i\,\omega\,t} - \frac{\omega_k^2}{\omega_k^2 - \omega^2}\,\epsilon + a_1\,e^{-i\,[(\omega\,-\,\omega_k)\,t\,+\,\phi_1]} + a_2\,e^{-i\,[(\omega\,+\,\omega_k)\,t\,+\,\phi_2]}$$

But so far we only have the value of $\overline{R}$ as referred to axes revolving positively with speed ω. If we wish to find $\overline{R}$ in relation to fixed axes, or $\overline{R}\,\phi$, it is necessary to multiply R by $e^{i\,\omega\,t}$, which is the unit vector revolving with the axes, so that :—

$$\overline{R}\,\phi = R\,e^{\,i\,\omega\,t}$$

which gives, finally, taking into account that $\omega_k^2 = \dfrac{E}{m}$:—

$$\overline{R}\,\phi = \frac{m\,g}{E} - \frac{\omega_k^2}{\omega_k^2 - \omega^2}\,\epsilon\,e^{\,i\,\omega\,t} + a_1\,e^{\,i\,(\omega_k\,t\,-\,\phi_1)} + a_2\,e^{-i\,(\omega_k\,t\,+\,\phi_2)}$$

Therefore the centre of gravity is subjected to :—

1. A deflection in the direction of gravity, the value of which is equal to $\dfrac{m\,g}{E}$, which is that called forth by the weight of the disc.

2. The ordinary circular motion, first centrifugal when ω increases, but remains below ω_k, the critical speed, then centripetal when ω continues to increase above ω_k.

3. An elliptic motion having a periodicity ω_k. This motion is that which the disc itself would take if it did not revolve, but were merely displaced from its position of equilibrium—this is, its vibratory motion proper.

This latter motion can be damped or excited by pulsations having a periodicity ω_k, or a periodicity in simple proportion with ω_k. The disc and the shaft may thus vibrate at speeds different from ω_k; but on the assumptions on which we have based our treatment, it is not gravity which produces these vibrations. In the expression $R\,\phi$ is embodied the principle of the independence of the effects of the forces.

Yours faithfully

J. Danis.

Compagnie Générale Transatlantique, St. Nazaire.

To the Editor of Engineering,

Sir,—I observe that this subject is still attracting a very regular correspondence. In your issue of May 5 Dr. Barclay gives a very interesting summary of causes leading to excessive vibration, which will be of undoubted value to turbine engineers. He has apparently had considerable experience of trouble due to constructional faults, and, of course, under these circumstances may consider himself justified in remarking "that the man to be sent for is the engineer, and not the mathematician." Not only will the former be more readily available, but since the fault is really his, he ought to be given the opportunity to correct it. Nevertheless, if there is evidence to show a possibility of troublesome vibration at a definite calculable speed, it is the designer's place to avoid it.

Like Dr. Barclay, I have noticed the complete absence of guidance in the literature of this subject in the matter of critical speed determinations for practical cases of more than two bearings. The graphical computation for the general case of a continuous shaft with any loading on three or four bearings is simple enough, although somewhat more lengthy than the well-known process for a two-bearing configuration; but the introduction of a rigid coupling and the raising of an outer bearing must introduce rather annoying complications. This latter is a rather peculiar condition.

In the letter from Mr. Wallace in your issue of May 12 there appears an interesting confirmation of the accuracy of the ordinary graphical method of calculating critical speeds. The use of narrow ring bearings would make the problem quite definite in this case, but I would suggest that, if Mr. Wallace has the apparatus available, he should be able to solve a somewhat important problem by running tests with various lengths of bearings, having different running clearances. Mr. Wallace also states that he originally suggested the method which I have used in Case 1 of my paper. I was unaware of this, having obtained the method from an article by Professor Morley in vol. lxxxviii. of Engineering. I think the principles on which this method depends are due to Lord Rayleigh. In practice it is common to calculate the critical speed by the application of Baumann's rule to the maximum static deflection obtained in the usual manner.

In the current issue of Engineering there appears a letter from Professor Jeffcott enlarging somewhat on the views advanced in his original letter; and I have to thank him for stating more fully the application of his idea to my second method of treatment. I had fancied I had detected a certain difficulty in this. Professor Jeffcott seems still to consider his treatment of rotation about the gravitationally deflected position quite valid. I have said that in considering rotation about this position gravity must be entirely neglected, since the assumed centre of rotation allows for it. He claims that his treatment is tantamount to this, but this hardly appears correct on examination. In connection with this question he should note the reference to Föppl's equations, towards the end of Dr. Stodola's letter, in the issue of Engineering for April 21.

I note that Professor Jeffcott admits Dr. Chree's result and also the possibility of resonance "at *any* speed whatever, provided an external rhythmic action of appropriate frequency be introduced." It would surely be quite natural to expect this effect when the appropriate period is that of revolution. In my paper I have merely endeavoured to show that the disturbing action could be due to gravity; and is it not reasonable to suppose that a unidirectional force like gravity must have some effect, even if it does only show itself in the mathematics? But I do not see why Professor Jeffcott should hesitate to allow this explanation of the occurrence, even while denying the effect of gravity, since the disturbing force might conceivably arise in a variety of ways due to the rotation. Instead of this he seemingly attributes the effect to a location of the nodes of vibration completely outside the bearings. While finding such an explanation too great a tax on the imagination when carried to an extreme, as in this case, I am glad that Professor Jeffcott has given prominence to this idea of looseness in bearings causing variation of the nodal distance. It is distinctly valuable, and ought to be specially emphasised for the sake of those turbine designers who at all times calculate critical speeds with the nodes at the inner edges of the bearings.

By this time Professor Jeffcott will probably have seen the developments in this discussion subsequent to his original letter; and particularly the letters from Dr. Stodola and Mr. Carter, from which he will learn that there are still other aspects of this matter. Indeed, it looks as if my article had performed the function of the surgeon's knife, and "blooded" this subject with such results as would seem to indicate a certain necessity for the operation.

I am, Sir, yours faithfully,

Airdrie, May 22, 1916. Wm. Kerr.

"SPUR-GEARING."

To the Editor of Engineering.

Sir,—Referring to the notice of the discussion on the above paper, on page 494 of your issue for May 26, the short paragraph about the centre of the middle column does not correctly interpret what took place, and the last sentence should read somewhat as follows :—

"His experience of *cast* teeth showed the average error to be in the neighbourhood of four-thousandths to five-thousandths of an inch between adjacent teeth, the *inference* being that, as had already been suggested by Mr. Sharp, the error between adjacent teeth with *accurately* cut gearing would be in the neighbourhood of one-tenth of one-thousandth, or even less."

Further down the same column, the heavy gearing I quoted was 7½ in. pitch, not ½ in. pitch, with an addendum of 1½ in., which is practically one-quarter of the pitch, and similar to the proportions upon which Table I. of my paper is based.

I remain, yours truly,

Daniel Adamson.

Hyde, Cheshire, May 29, 1916.

To the Editor of Engineering.

Sir,—There seems to be an impression in many quarters that short teeth for spur and bevel gearing are more durable than long ones. The first part of Mr. D. Adamson's paper, which appeared in your issue of May 26, will tend to strengthen the impression, though whether Mr. Adamson intended to lend the theory his support is not quite clear. Supposing the angle of thrust to be settled, however, I think there is a strong case, from the point of view of durability, for making the tooth as long as possible, the limiting considerations being that, in the case of the smallest pinion of the set, there shall not be excessive undercutting, nor shall the points of the teeth run to a knife-edge, but shall have a reasonable thickness

The usual arguments in favour of short teeth are: (1) that contact between the teeth takes place nearer the pitch circle, where the sliding of the teeth over one another is a minimum; and (2), that since the bending moment to be taken by the tooth varies directly as the length of the tooth, a short tooth is relatively stronger than a long one, so that a smaller pitch may be used, thus bringing more teeth into action.

Against these arguments it may be urged: (1) that with the shorter teeth, assuming for the moment no reduction of pitch, there will be fewer teeth in contact, and heavier loads near the pitch circle. Although the tops of the long teeth are less efficient than the central portions, they nevertheless relieve the central portions of a part of the load. (2) A reduction in pitch effects only a small increase in the number of teeth in action (assuming that the height of the tooth is reduced proportionally to the pitch), while there is considerable loss of surface and concentration of load resulting from the reduction in the height of the tooth. (3) Since short teeth are favourable to small pinions, there will be a tendency to adopt small pinions, thus again reducing the number of teeth in gear and concentrating the wear on a small number of teeth.

But supposing the number of teeth not to be reduced, the claim on behalf of the short tooth apparently implies that for a pinion of given number of teeth and pitch, if the teeth are shortened the load may be increased, and in spite of the increased load and reduction in wearing area, the pinion will last longer. Such a claim seems to require a more rigid demonstration than it usually gets.

Yours faithfully,
W. W. PADFIELD.

42, Lower Oldfield Park, Bath.

"THEORY AND PRACTICE IN THE FILTRATION OF WATER."

TO THE EDITOR OF ENGINEERING.

SIR,—Mr. William Paterson hardly improves his case by his renewed attack on the above paper in his letter which you published on May 26.

Is he not confusing "matters in suspension" with "matters in solution"? These two make up the "total solids," as clearly pointed out in the author's letter published on May 19.

It would be interesting if Mr. Paterson would explain now the final filters produce the silt which, as the tables show, has already been removed by pre-filtration.

Percentage figures as to bacterial purification may be misleading, as Mr. Paterson suggests, but his admission that the process to be employed at Poona may still leave 1000 dangerous bacteria in the filtered water appears to me to support the conclusions arrived at by the author of the above paper.

Yours faithfully,
H. B. S.

"INDUSTRIAL DEVELOPMENT."

TO THE EDITOR OF ENGINEERING.

SIR,—After dealing with this subject from the point of view of the engineering trade in last week's issue, I desire to deal with the question further from a national point of view.

Before entering upon any details of what I propose in this direction, I think it is necessary to premise that while the treatment of the domestic difficulty has to be more or less on the lines of the socialists' ideal, cosmopolitanism—or international socialism—must be ruled out. The diversity of the world's races is too pronounced, the ambitions and qualities of even the European races too diverse, to discard for the present the principle of nationality

On the other hand, this diversity of civilisations in a world in which the intercourse between nations is becoming daily more rapid and easy, is developing into a source of embarrassment to the higher grade civilisations by threatening them with the importation of cheap labour from the populous East.

Australia and America, populated chiefly by men of our own race, are already alive to this difficulty, as they lie nearer the centres of those more primitive populations.

How is the more complex society to defend itself against the irruption of the simpler one which is content with a lower scale of civilisation? Its only chance is by perfecting its methods in the arts which have raised it in the scale of civilisation, and, above all, by preserving its unity in collective action. Here, again, the old policy of *laissez faire* is hopelessly discredited.

Our Dominions beyond the seas have shown a true appreciation of the danger which threatens them and us alike, with that sound political instinct which is characteristic of the race. The misuse of the engines which science has put into the hands of civilised man is not to be tolerated. The domination of one particularly rigid form of civilisation is not to be allowed; but the methods of that form of civilisation will have to be partially adopted as a bulwark against its acknowledged strength.

The Dominions have answered the challenge by the practical exhibition of unity, of collective effort, in war. No more for this country the luxury of muddling through, of the acquisition of colonies in "a fit of absence of mind." The possessions we have, which are essential to industrial development of any kind, can only be retained by hard fighting now, and by hard thinking when the fight is done.

The most precious possession of all our spiritual liberty is the most difficult of retention under the conditions of grinding competition which our enemy seeks to fix upon the neck of humanity. But it is no less than that which is really at stake. It is the moral factor which will win the war, because it is also the factor which our enemies have not only ignored, but dismissed from consideration with contempt. To preserve it will be the task of the statesmen upon whose shoulders the burden of the reorganisation of European civilisation will descend.

It is not wandering from the consideration of Industrial Development to consider how this is to be achieved, because under the new political conditions the old conditions of industry must be altered to conform with them; and in the following suggestions I must be understood as offering them for adoption by the British Empire as an indivisible whole, not merely for the United Kingdom.

The first consideration will be such assurance of international peace as will prevent the recurrence for many generations of such a nightmare as we are now passing through. Exhaustion both of population and capital will be the natural guarantee for a couple of generations at least. But I think more than this will be required by the conscience of civilised humanity. I do not think immediate disarmament is practicable. To put it on merely economical grounds, the nations which have sunk capital in munition works must see some return for their money; they must also retain the power to repress any further encroachment on the liberties of the nations as settled at the peace. This country, in spite of old traditions, will have to accept national service as the price of her continuance among the great Powers.

But I do not think this need dishearten us. The example of France is an encouragement to all faint hearts, and it may be a blessing in disguise if, as I think, it reforms our system of class education by making the Army the finishing school of our youth. It is evident that a nation in arms is a nation at unity with itself. It is further not beyond the dreams of reason that instead of being a hindrance to the subsequent civil career, the Army, under wise direction, might become the supreme technical university of the nation.

Without entering into too much detail, I will try and indicate the general lines upon which this perhaps startling theory can be realised.

I learnt the interdependence of civil and military craftsmanship when in command of a battery of artillery. Such trades as farriery, saddlery, blacksmiths and engineers' work, the care and grooming of horses, the use of the Morse code in signalling as practised by post-office clerks, the skill at reading new instruments of precision in the elevation of the gun—acquired in the fitting and turning or boiler shop of an engineering establishment—all these civil accomplishments contributed to the efficient working of the battery from a military point of view. If they are needed in that particular arm of the Service, those who are responsible for its efficiency are also capable of teaching the necessary skill to the raw recruit in these various branches of the arts; and teaching them, mind you, as an art, not as a dodge to hurry through scamped work behind the back of the foreman, to the detriment of a master's reputation.

To pass the whole manhood of the nation through such a school means reorganisation on a very great scale; but I do not think it impossible to combine the existing educational and military systems, with time and patience. In the outset it will be wise to leave the present Universities and the present Navy and Army organisations, as far as the Regular Forces are concerned, much as they are.

All highly qualified students who are capable of research work in science, history, law, medicine or theology, should be regarded as belonging to reserved occupations, and excused military duty after matriculation approved by the University faculties concerned. Also the Regular Army and its reserve, special reserve, and reserve of officers must be maintained at the old professional level of excellence, as a depôt for our garrisons overseas, and the nucleus of an ever-ready mobile expeditionary force. To increase its educational value in times of peace, and make it ready for sudden expansion in case of war, the establishment of staff and regimental officers should be largely increased above the normal proportion hitherto considered necessary.

I am not qualified to speak of naval matters, but I venture to suggest that the experience of the present war and the close brotherhood in arms of the Mercantile Marine with the Navy will break down to a large extent the distinction between the professional-military and ordinary seaman, so that any remarks I may make regarding the Regular and Territorial Services may be held to be good for all seafaring members of the Empire. Having, therefore, left the three long-standing pillars of our civilisation—the Navy, the Regular Army, and the Universities—to develop on their well-established lines, we must consider the relation of the Territorial Force, which is to become the University of the rest of the nation, to the various classes which it will have to instruct in the arts of peace as well as war.

In the first place I would lower the age of admission to 16, to enable the artisan's son to complete his military training when he is 19. In a manufacturing country such as we have become, it will be necessary to increase the proportion of the scientific branches of the Service, the Engineers and the Artillery, to a larger proportion than is held necessary by the present scale of army establishments; nor do I think that this will be disadvantageous from a military point of view in the light of modern warfare. Work on munitions of war might be regarded as military service, and the time served in such shops, or the Royal Regiments of Engineers and Artillery, be counted as qualifying towards the usual period of apprenticeship in the trades concerned. For the sons of commercial or professional men the time of admission might be made later, to give them the chance of qualifying for the reserved occupations at the Universities if desired.

The remainder of the Force, Yeomanry and Infantry, would be for all those whose subsequent occupations would be agricultural, clerical, commercial, or unskilled labour. The organisation and training of this larger body of the Line requires more ingenuity than that of the more specialised branches of the Service.

Inasmuch, however, as trenching and road-making make a large demand upon modern armies, the cognate industry of agriculture would be benefited by the employment of such troops upon the land; and drawn as they are in the majority of cases from urban populations, such employment would benefit the health of the men so employed, and even give to some a taste for such pursuits which they would never have acquired in city life. Topography, and all the training system as invented by Sir R. Baden Powell for his scouts, would form part of their instruction, and for those who desire, and could afford to have the fees deducted from their pay, I think instruction in modern languages, surveying, and a certain amount of commercial education, could go hand in hand with their military work. The administration of such an organisation would absorb no small percentage in purely clerical work, though I would strongly deprecate the adoption of the cumbrous methods of the War Office to these details, which should be superseded by a system more in consonance with the economy and methods of civilian business.

Without, as now, congesting the railways at the periods of public holidays, such a force could be trained in the summer months in the field, in such exercises as mobilisation, concentration, musketry exercises, and field manœuvres.

The whole object of this sketch of the possibility of converting the Territorial Army into a National Education Department is with a view to combine the necessity of adapting National Military Service to general educative ends; and I think if a commission were sent to Switzerland to study the methods employed in that country they would find that such a proposal is not wholly Utopian, but feasible. They would find that National Service, when adopted in a free country, with the necessary elasticity required in its regulations to prevent undue hardship and secure the minimum of interference with the civilian business of the nation, is possible, and compatible with a very high efficiency as a fighting machine.

Its greatest attraction, to my mind, is its educative influence in the direction of collective effort. It will combine habits of discipline with the destruction of those class prejudices which so weaken our administrative and commercial success. That this is a necessary preparation for industrial development after the war is shown by Mr. Cox's concluding sentences. Such or such-like educational reform is the first consideration.

Yours truly,
"VENATOR."

GIROD ELECTRIC FURNACES AT THE BETHLEHEM WORKS.—The Bethlehem Steel Company has just taken out the first heat from the 10-ton Girod electric steel furnace at its plant at South Bethlehem, says the *Iron Age*. The furnace is the largest of its type in the United States, and is expected to become a valuable adjunct of the Bessemer converter and the open-hearth furnaces as a means for refining the molten steel. Plans call for three such furnaces in the completed plant.

CARBON MONOXIDE DETERMINATION.—In analyses of producer gas the CO is generally absorbed by ammoniacal cuprous chloride. In the *Chemiker Zeitung* of May 10, 1916, Fritz Hoffmann points out, however, that this absorption is never complete, and that it has in practical working remained below the real value by as much as 4 per cent. As the error would affect the other percentages, he suggests to check the result, whenever possible, by complete combustion tests. This would be laborious, but a thoroughly reliable absorbent for carbon monoxide is not known.

MAXIMUM COAL PRICES AT PANAMA.—According to the *Canal Record*, the Governor has published a circular, dated April 17, 1916, establishing, with the approval of the Secretary of War, maximum prices to be charged for coal sold to ships by lessees of coal storage areas at the Canal terminals. The circular states that "a maximum price per ton will be fixed by the Panama Railroad. All coal in storage owned by individuals and companies will be subject to purchase by any vessel using the canal. From July 1, 1916, and thereafter until further notice, the maximum price for coal supplied by individuals and private companies to steamships at the terminal ports of the Panama Canal will be cost, plus 25 per cent. Lessees will be required to furnish the Panama Canal with such information as will enable the Canal authorities to check the maximum price on this basis."

ALLOY STEEL RAILS.—We read in *The Engineering and Mining Journal*, New York, that the production of alloy-treated steel rails in the United States has shown some remarkable fluctuations. It reached its maximum in 1910, when the total was 257,324 gross tons, or 7.1 per cent. of the whole output. In 1911 the total was 153,980, tons and in 1912 it was 149,267 tons, all but a few tons in those years being titanium steel. In 1913 the total was 59,515 tons, 47,655 tons being titanium steel; in 1914 it was 27,937 tons, 23,321 tons being titanium steel. In 1915 it fell to 24,970 tons, 21,191 tons being titanium steel, and 3779 tons manganese steel. Nearly all the alloy steel rails were heavy-section, 85 lb. or more to the yard. The greater part of the titanium steel rails manufactured in 1910, 1911 and 1912 were for one company, and no statement has been made of the wearing results.

SPUR-GEARING.*

By DANIEL ADAMSON, Member, of Hyde

(*Concluded from page* 513.)

Allowable Working Stresses.—As to allowable working stresses in the teeth of wheels, there is a great diversity of opinion, due no doubt to the varying standards of workmanship in the examples used by the various authorities for their bases.

E. R. Walker in 1868 published some data, based upon a breaking load of 2000 lb., for a tooth 1 in. wide by 1 in. pitch (corresponding to a maximum fibre stress in the teeth of about 15,000 to 33,000 lb. per sq. in., depending upon whether a pinion tooth or a rack tooth is taken, or, say, 24,000 lb. as an average), with a table giving factors of safety recommended, varying from 3 at very slow speeds to 14 at 40 ft. per second (2400 ft. per minute) (J. H. Cooper's paper in the Journal of the Franklin Institute, 1879, vol. 108, pages 15, 16). (See Fig. 13, page 539.)

F. Reuleaux's "The Constructor," originally published over 50 years ago, gives permissible stresses as follow :—

Wood	...	...	2,544 lb. per sq. in.
Cast iron	...	...	4,240 ,, ,,
Steel	...	...	14,112 ,, ,,

These are for speeds not exceeding 100 ft. per minute, and are to be reduced for higher velocities down to about half their value for a velocity of 2500 ft. per minute.

In 1892 Wilfred Lewis published a table (Proceedings, Engineers' Club of Philadelphia, 1893, vol. 10), suggesting working stresses as follow :—

Cast iron ... 8,000 lb. per sq. in. } in outer fibres due
Steel ... 20,000 ,, ,, } to bending

for velocities of 100 ft. per minute or less, and these are to be reduced to about one-fifth for a velocity of 2400 ft. per minute. (See Fig. 14.)

These values correspond with E. R. Walker's recommendations, and it is a remarkable fact that Lewis's paper, which is still acknowledged (Marx's paper, Transactions of the American Society of Mechanical Engineers, 1912, vol. 34) to be the standard work of reference on this subject, should be based upon empirical figures, that so long ago as 1868 had been in use for several years (J. H. Cooper's paper, Journal Franklin Institute, 1879, vol. 108, pages 15-16). (See also Appendix I., below.)

Maximum Speeds.—The maximum speeds allowed by different authorities also vary considerably, owing, no doubt, to the different experience of each individual.

C. W. Drake (*Electric Journal*, 1912, page 554) states that noise begins at 600 ft. per minute, but does not become disagreeable under about double this speed.

G. J. Leire (*Machinery*, July, 1905, page 565) says that to avoid noise the pitch-line speed ought not to exceed 1000 ft. per minute.

W. H. Thornbery, M.I.Mech.E. (Staffordshire Iron and Steel Institute, April 12, 1902), gives 1800 ft. per minute as the greatest speed at which ordinary cast-iron wheels may be safely run, and up to 3000 ft. per minute for machine-cut wheels. The same authority quotes examples up to 4000 ft. and 5000 ft. per minute, but recommends caution before adopting such speeds.

Emile Geyelin (Proceedings, Engineers' Club of Philadelphia, 1894, vol. 11, page 142) gives particulars of bevel-wheels at Niagara transmitting 1100 horse-power at $\frac{260}{200}$ revolutions per minute where mortise-wheels were adopted because of the expected rapid variations in the load. The wheels have 43 and 33 teeth respectively, 5½ in. pitch and 20 in. wide, with a pitch-line velocity of 3930 ft. per minute. E. Graves, six and a half years later (Proceedings, Engineers' Club of Philadelphia, 1901, vol. 18, page 5) refers to the same wheels as running satisfactorily, except that the wooden teeth only last from six to eight weeks.

E. Graves gives in the same journal (vol. 18, page 56) particulars of some cast-steel bevel-wheels running in the same room as the above, and which had been put to work about two years later. These transmit 1300 horse-power at $\frac{260}{200}$ revolutions per minute. The teeth are 5 in. pitch, 20 in. wide, and the velocity is 3900 ft. per minute. Their wearing power as regards abrasion was quite satisfactory, but troubles arose from time to time through the teeth breaking out. The normal stress due to the transmitted load alone works out at 2100 lb. per sq. in., or only one-tenth of the allowable stress under a static load, or, say, perhaps one-fifteenth to one-twentieth of the elastic limit of the material, or one-thirtieth of the ultimate breaking stress.

That a velocity of 2500 ft. per minute is quite feasible is proved by an example quoted by Christie (Engineers' Club of Philadelphia, 1901, vol. 18, page 44), where a pair of spur-wheels transmit 3300 horse-power at 260 revolutions per minute with a pitch-line velocity of 2500 ft. per minute, a load on teeth of nearly 2100 lb. per in. of face, and a maximum fibre stress due to transmitted load of 6300 lb. per sq. in. (assuming one pair of teeth in action). The pinion was made from a fluid-pressed steel forging having the following analysis :—Carbon, 0.36 per cent.; manganese, 0.51 per cent.; silicon, 0.27 per cent.; phosphorus and sulphur, each below 0.03 per cent. The wheel was an annealed steel casting having the analysis : carbon, 0.47 per cent.; manganese, 0.66 per cent.; phosphorus and sulphur, each below 0.5 per cent.

On the New York Subway (Litchfield's paper, Transactions of the American Society of Mechanical Engineers, 1908, page 967) teeth failed by breakage before they were very far worn, the maximum stress running to 13,370 lb. per sq. in. (calculated on the original size of tooth, or about 16,500 lb. on the worn tooth) with material having an elastic limit of 45,000 lb., the pinion running at about 550 revolutions per minute, or 1168 ft. per minute at pitch circle.

An example that has come to the author's notice in private correspondence (E. and G., Bolton, November, 1910) is a pair of machine-cut bevel-wheels, ratios 3 to 1, transmitting 1500 horse-power; pitch-line velocity, 3000 ft. per minute; teeth, 10½ in. wide; load, 1570 lb. per in. of width; the first wheels were made 3½ in. pitch and transmitted 600 horse-power satisfactorily, but failed under occasional peak loads of 1500 horse-power, and were replaced by others of 2½ in. pitch, which proved quite satisfactory, the other conditions remaining unaltered.

Another example that has given trouble is a set of spur-gearing to transmit 120 horse-power at $\frac{488}{110}$ revolutions per minute, $\frac{156}{35}$ teeth 2 in. pitch, 8 in. broad, velocity 2860 ft. per minute, load 172 lb. per in. of face. Paper pinions and also a cast-iron one (cut teeth) failed in use, and a steel pinion was found to be too noisy. The paper pinions lasted about 7000 working hours.

It may be pointed out that, while it is the irregularity in the teeth that gives rise to noise in the first instance, yet, if the construction of the wheel is favourable to resonance, the noise will be multiplied to a disagreeable extent.

Durability.—Consideration, as yet, has only been given to permissible loads and speeds having regard to risk of failure from too high stresses, but some guidance is also necessary for the designer in respect of durability.

Dr. Otto Schaefer (*Dingler's Polytechnisches Journal*, 1910, vol. 325) gives a table showing the variation in loading, according to the number of revolutions estimated to be made by a wheel before wear has so weakened the teeth as to bring the stress due to bending up to a predetermined maximum. The article refers to hoisting machinery in particular. Table II. (below) gives Dr. Schaefer's values for K (a variable dependent upon the material used and the circumstances of the drive) in the simplified formula for strength of teeth :—

TABLE II.—*For K.*

(*Converted into British Units.*) *Maximum Stress Allowed.*

Total life in millions of revolutions.	17,000 lb. per sq. in.	14,000 lb. per sq. in.	11,400 lb. per sq. in.	8500 lb. per sq. in.	5700 lb. per sq. in.	2850 lb. per sq. in.
0	1350	1120	898	685	455	228
1	1292	1080	870	655	442	228
2	1238	1040	840	640	442	214
3	1180	1010	812	626	428	214
4	1138	968	798	612	428	214
5	1094	940	785	598	413	214
6	1051	910	770	598	413	214
7	1023	883	742	584	413	214
8	997	868	726	570	399	214
9	968	840	713	555	399	214
10	940	826	698	555	384	214
12	883	782	670	526	384	200
14	840	740	640	512	370	200
16	797	712	612	498	356	200
18	769	685	598	484	356	200
20	740	655	570	470	342	200
30	612	555	485	442	314	185
40	526	484	428	370	285	172
50	413	384	356	299	242	157
60	342	327	299	270	214	142
100	297	284	256	226	200	134
120	257	242	226	212	171	123
150	228	212	200	185	157	111
200	185	171	157	142	128	97
250	142	142	137	127	111	86
300	128	123	120	109	100	77
400	101	98	94	88	80	64
500	84	81	81	74	69	56

$$W = P \times F \times K,$$

where W = safe working load in pounds,
P = circular pitch in inches,
F = width of face in inches,
K = as above.

In explanation of the table, it may be observed that the number of revolutions made by a pinion running at, say, 500 revolutions per minute for 10 years of 300 days of 10 hours, working for one-third of the time (as, for example, on a crane), amounts to $500 \times 0.6 \times 10^6$, and this figure (multiplied by, say, 0.5 on the assumption that the gearing is only loaded to one-half its full capacity on an average) gives 150×10^6. On referring to the table it will be seen that for a life of 150×10^6 revolutions the value of K in the above formula should be taken at 228 for steel at 17,000 lb. per sq. in. maximum working stress in the worn tooth, and 157 for cast-iron at 5700 lb. per sq. in.

Dr. Schaefer suggests maximum stresses of about 17,000 and 14,000 lb. per sq. in. for forged steel and steel castings respectively, and 5700 lb. per sq. in. for cast iron, and in the original article shows by comparison with actual examples, and also with an accepted formula by Bach, that his deductions are reasonably correct.

[These values seem very low for steel.]

Conclusion.—Reference has been made to Reuleaux and to papers by Lewis, Lasche, Schaefer, and Marx, all of whom, in one way or another, directly or indirectly, make provision for reducing the estimated working stresses in the teeth when these are to run at higher speeds, and each author is able to point to more or less satisfactory proof of the reliability of his data, so that it may be reasonably assumed that all contain a considerable amount of truth, although the question has been approached from different directions.

Lasche makes the most helpful suggestion by indicating how the stresses induced by variations in the angular velocity of wheels, due to unavoidable errors in pitch, may be many times the transmitted load alone, and also that these excesses will vary as the square of the velocity. Examples have been quoted of wheels that have failed by breakage of steel teeth after a few months' work, although these failures could not be accounted for by the peripheral load due to the power transmitted, and in fact an example is given where steel teeth (when gearing with wooden mortise teeth) have transmitted equivalent loading satisfactorily for years, the mortise teeth absorbing the shocks, but having very short lives in consequence.

Assuming that Lasche is correct, and that the varying angular velocity resulting from inaccuracies in the cutting of the teeth of wheels causes excess loads which are large compared with the normal loading, the resulting stresses must be taken as practically equal in magnitude and of opposite sign. Under these conditions Dr. Unwin shows ("Elements of Machine Design," 1909, page 41) that the breaking stress (for one million changes of load) is only about one-half the primitive yield-stress of the material, because of the Wöhler effect of the repeated stresses. (See also ENGINEERING, vol. xi., 1871, for the most complete record in English of Wöhler's work.)

Referring now to Graves' examples on page 22, if the transmitted load (equal to one-twentieth of the elastic limit of the material) is raised by these alternating stresses to one-half the elastic limit or anything of that order, it seems that the excess load (in this particular instance) at 3900 ft. per minute is ten times the transmitted load. Arguing largely from theoretical grounds, Lasche showed in 1899 that the possible excess load induced by an actual measured error of pitch of 0.02 inch in a wheel of about 1½ in. pitch running at 2460 ft. per minute amounted to 28 times the peripheral transmitted load. (See Appendix II.)

It seems to the author a very reasonable assumption to make that the additional stresses thus induced in a wheel running at a high velocity are very large, and accordingly it is not sufficient to consider the stress due to the transmitted load, and to reduce this merely for the higher velocities. In the examples just quoted, where the excess loads are suggested as being 10 times, or 28 times, the transmitted load, no reduction in the stress originally allowed would meet the case. However small the transmitted load the wheels would break, due to the alternating stresses alone. What is wanted is a standard of accuracy for different velocities. If 0.02 in. in a pitch of 1½ in. (say 1¼ per cent.), in Lasche's third example, can cause trouble at 2460 ft. per minute, then to secure a factor of safety of, say, three, the inaccuracy must be reduced to less than ¼ per cent. for this velocity, and if a velocity of, say, 3900 ft. is desired (as in Christie's example) the error must be reduced to less than 0.2 per cent., the excess load increasing directly as the amount of inaccuracy, and as the square of the velocity.

Figs. 13, 14, and 15, page 539, show the allowable working stress, according to Walker, Lewis, and Marx respectively, while Fig. 16 embodies the conclusion arrived at in this paper.

H. F. Moore and F. B. Seeley have recently shown (American Society for Testing Materials, June, 1915) that it is reasonable to assume that the allowable working stress should vary inversely as the one-eighth power of the expected number of repetitions of stress during the working life of the piece concerned. This means that in addition to improving the standard of accuracy of *high-speed* gearing so as to reduce the excess loads resulting from variations in angular velocity, there must be further improvement in order to reduce the total stress to such a figure as will allow the required number of rotations (repetitions of stress) to be made without endangering the safety of the mechanism concerned, the number of rotations being generally greater per unit of time with *high-speed* gearing than with low-speed.

The author considers that these somewhat detached notes are hardly worthy of being called a paper, being in fact merely a collection made during the past 20 years of information and references for the author's own guidance in the design of electric overhead travelling-cranes of varying capacities. He has endeavoured to show that the present state of knowledge on this important mechanical and metallurgical subject is far from complete, and hopes that he has given some indication of the direction in which members can afford valuable help, by giving examples from their experience of successful and unsuccessful practice in the use of spur-gearing of different materials under varying conditions.

The thanks of the author are due to Mr. Thomas Bevan, B.S. (Tech.), for assistance in reading the proof, preparing the illustrations, and revising the Appendices.

APPENDIX I.

LIST OF REFERENCES (ARRANGED CHRONOLOGICALLY).

Euler's "New Commentaries," vol. xi., St. Petersburg, about 1760. According to Willis the involute form was first suggested by Euler in his second paper on "The Teeth of Wheels."

Camus on "The Teeth of Wheels," translated by G. I. Hawkins. Second edition, published by J. S. Hodson, London, 1837.

Professor Robert Willis: Proc. Inst. C.E., 1838, vol. 2.

Edward Sang: "New General Theory of the Teeth of Wheels." Published by A. and C. Black, London, 1852.

J. H. Cooper: Journal, Franklin Institute, 1879, vol. 108, pages 15-16. Paper on "Power Transmitting Mechanism." The following is taken from the paper :—

From "Practical Rules for the Proportions of Cog-Wheels and Shafting," by E. R. Walker (of Haigh Foundry, Wigan), Newcastle-under-Lyme, 1868, we select the following observations and rules, changing the notations :—

"The results will be found to give a good average margin of strength with ordinary materials. The rules are based upon and have been tested by a large number of examples in actual operation, and they have been used in a considerable practice for some years.

* Paper read before the Institution of Mechanical Engineers, Friday, May 19, 1916.

"To find the extreme strain which the teeth of any wheel are capable of transmitting.

Calling X = breaking load of tooth in lb.
S = working " " "
p = pitch of teeth in inches."
f = face " " "
m = 3 for very slow" speed without shock.
" = 4 when rim of wheel runs 3 F. p.s.
" = 5 " " " 5 " "
" = 6 " " " 10 " "
" = 8 " " " 15 " "
" = 10 " " " 20 " "
" = 12 " " " 30 " "
" = 14 " " " 40 " "

we have $X = 2000\ p.f.$ . . . . (1)

"The extreme or breaking load being found, and the speed given to find the working load the wheel should bear,

$$S = \frac{x}{m}$$

[Mr. E. R. Walker was manager of the Haigh Foundry, Wigan, about 1868, and is believed to have afterwards become manager of Talk-o'-th'-Hill Colliery, in Staffordshire.]

of speed by pressure divided by circular pitch, that is, $\frac{\text{Velocity} \times \text{Load}}{\text{Pitch}}$, shoul not exceed 1,000,000.

E. Graves: Proc. Engineers' Club of Philadelphia, 1901, vol. 18, page 57.

American Machinist: vol. 24, page 1079, October 12, 1901. List of proportions and strength of spur-gear teeth adopted by Joseph Adamson and Co.

Robert A. Bruce, Lieut. R.N.V.R. (*American Machinist*, 1901, vol. 24, page 1140), furnished an article advocating increased obliquity and shorter teeth.

American Machinist, 1901, vol. 24, page 689. Table of Strength of Gear-Teeth in terms of diametral pitch.

Iron Age: 1901, February 28, page 19.

American Machinist: Vol. 25, February 15, 1902, page 145, "The Strength of Shrouded Teeth," by Wilfred Lewis. A single shroud may add 10 per cent., and double shroud 30 per cent. to the strength of teeth, but the space occupied would be better employed in increasing the width of the face of the teeth.

W. H. Thornbery (Staffordshire Iron and Steel Inst., 1902) gives several different values varying from about 400 lb. to 800 lb. per in. of width on cast-iron teeth of 4-in. circular pitch.

Fig. 13 to 15. RATIO OF ALLOWABLE LOAD TO VELOCITY.

Fig. 13. E. R. WALKER, 1868.

VELOCITY OF RIM OF WHEEL IN FT. PER MIN.	VERY SLOW WITHOUT SHOCK	80	300	600	900	1200	1800	2400
FACTOR OF SAFETY.	3	4	5	6	8	10	12	14
CORRESPONDING MAX. WORKING STRESS IN LB. PER SQ. INCH (ESTIMATED).	8000	6300	4500	4000	3200	2400	2000	1700

Note:-The actual values vary from 60% to 150% of these values depending upon whether the teeth of 12 tooth pinions or racks are taken.

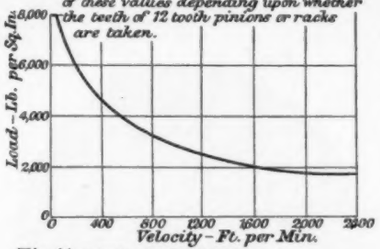


Fig. 14. WILFRED LEWIS, 1893.

VELOCITY OF TEETH IN FT. PER MIN.	100 OR LESS	200	300	600	900	1200	1800	2400
SAFE WORKING STRESS FOR C.I. IN LB. PER SQ. IN.	8000	6000	4800	4000	3000	2400	2000	1700

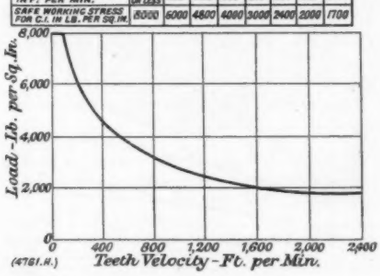


Fig. 15. MARX AND CUTTER FROM TESTS, 1915. BROWN AND SHARPE 14½ INVOLUTE CAST-IRON.

PITCH VELOCITY IN FT. PER MIN.	8000	100	200	300	600	900	1200	1800	2000
OB-EFFICIENT.	1·00	·795	·730	·675	·565	·500	·455	·410	·400
CORRES. MAX. STRESS WITH A FACTOR OF SAFETY OF 5 AT 0.	9600	7200	6600	6100	5100	4500	4100	3700	3600

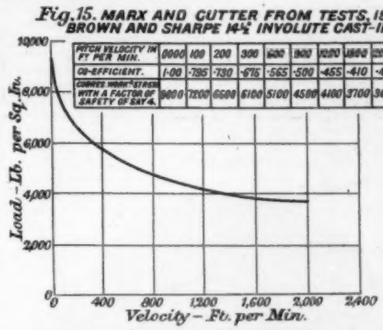


Fig. 16. RATIO OF ALLOWABLE INACCURACY TO VELOCITY. AUTHOR, SUGGESTED, 1916.

VELOCITY OF PITCH CIRCLE IN FT. PER MIN.	100 OR LESS	200	300	600	900	1200	1500	1800	2100	2400
INACCURACY IN % OF PITCH	5%	·176	·96	·94	·485	·12	·09	·065	·052	·042

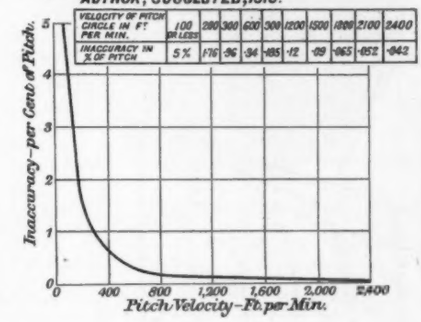


Fig. 17.

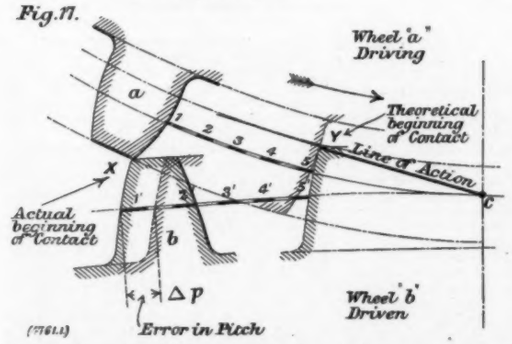
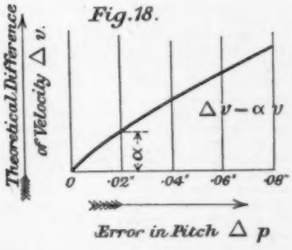


Fig. 18.



Michael Longridge: Annual Reports of Engine and Boiler Insurance Company, 1887-8-9.

Archibald Sharp: "Wheel Teeth," Proc. Inst. C.E., vol. 113, 1892-3, and vol. 121, 1894-5.

Wilfred Lewis: Proc. Engineers' Club of Philadelphia, Investigation of the Strength of Gear-Teeth, January, 1893, vol. 10.

Reuleaux, "The Constructor," 1893 edition, page 146, quotes Tredgold as recommending 400 lb. per in. of width, but adds that pressures as high as 1400 have been successfully used.

He also shows that $\frac{P \times N}{b}$ ought not to exceed 28,000, and may be reduced to 12,000 or even 6000. For wooden teeth he mentions 15/20,000, with an example given of 7000 to 8000 having run 26½ years (page 147).

Emile Geyelin: Proc. Engineers' Club of Philadelphia, April, 1894, vol. 11, page 142.

O. Lasche: Zeit. des Ver. Deut. Ing., 1899, vol. 43, page 1417. [Pages 9-17; and also Appendix II.]

Wilfred Lewis: "Interchangeable Gearing," Proc. Engineers' Club of Philadelphia, vol. 18, February, 1901, page 51.

Christie (Proc. Engineers' Club of Philadelphia, February, 1901, vol. 18, page 44, and in *Iron Age*, vol. 67, February 28, 1901, (page 19) gives an example 2100 lb. per in. of face at 2500 ft. per minute. $\frac{P N}{b} = 236{,}000$. Carbon, 0.86 per cent. Highest recorded velocity, 3900 ft. per minute for mortise-wheels—680 lb. per in. of face; life short. He suggests that the product These give the very low stresses of 1000 lb. to 2000 lb. per sq. in. of material.

Buchner: Zeit. des Ver. Deut. Ing., 1902, vol. 46, page 279.

H. D. Williams (*American Machinist*, 1903, vol. 26, page 257) wrote a paper on Measurements of Contacts, comparing the resistance to crushing of curved surfaces of different radii in contact.

William Kent: "Mechanical Engineers' Pocket-Book" (Seventh edition, 1904, pages 900-5). Several formulæ for calculating the strength of gear-teeth are compared and examples quoted of gearing running at high speeds up to 3000 ft. per minute.

Cheddle (*American Machinist*, 1905, vol. 28, page 220) gives his ideas as to relative loads on cast iron, gun-metal, cast steel, and forged steel, in the ratios of 1, 1½ and 2½ respectively, with modifications for speed and shock as in "Lifting Machinery."

G. J. Leire: *Machinery*, 1905, July, page 565.

C. H. Logue: *American Machinist*, 1907, vol. 30, page 804.

Thomas Humpage: "Manufacture of Spur-Gearing," Inst. Mech. E., July, 1908.

In Nicolson and Smith's "Lathe Design," published by Longmans, Green, London (1908), will be found on pages 155-162, an extended reference to Stribeck, Bach, and Lasche's investigations.

Robert H. Smith: "Design and Waste and Wear of Wheel Teeth," Society of Engineers, May, 1908.

R. E. Flanders (Trans. Amer. Soc. Mech. Eng., 1908, page 921) advocates shorter teeth and increased pressure angle.

N. Litchfield: Trans. Amer. Soc. Mech. Eng., 1908, page 967.

C. H. Logue: *American Machinist*, 1908, vol. 31, pages 95 and 115.

L. P. M. Revillon: Iron and Steel Inst., Carnegie Memoirs, 1908-9, vol. 1, page 160.

C. H. Logue (*American Machinist*, 1908, vol. 31, Parts 1-2, pages 95 and 115) considers the effect of wear as well as strength when calculating the size of gear-teeth.

Iron Age: Vol. 81, page 1232, April 30, 1908. Manganese steel gear-wheels and pinions that lasted five times as long as ordinary steel, on travelling cranes.

C. H. Logue (*American Machinist*, 1909, vol. 32, Part 1, page 917) suggests varying the working stresses for the teeth of wheels according to the method of construction and presumed accuracy of workmanship, but the figures given seem to be only personal opinions unsupported by evidence either of a practical or a theoretical nature.

R. Livingstone: *Electrician*, 1909, March 19, page 892.

W. C. Unwin: "Elements of Machine Design," 1909, Part 1, pages 41 and 399.

R. Plessing (Zeit. des Ver. Deut. Ing., 1910, Part 2, vol. 54, page 1682) advocates increasing the pressure angle, and points out how this can be done with existing generating machines, and shows, by calculation, the required difference in diameter, of base circle and side accordingly.

J. D. Steven: "Tooth Gearing," Inst. Mech. E., July, 1910.

Wilfred Lewis (Trans. Amer. Soc. Mech. Eng., 1910, vol. 32, page 803) refers to investigation by a committee, and gives a summary of experiments as far as carried out.

Otto Schaefer: *Dingler's Polytechnisches Journal*, 1910.

C. H. Logue: *American Machinist*, 1910, vol. 33, Part 2, page 527.

Eden, Rose and Cunningham: "The Endurance of Metals," Inst. Mech. E., October, 1911.

Rikli (Zeit. des Ver. Deut. Ing., 1911, vol. 55, page 1435): Tests of the efficiency of transmission by spur-gearing show that the loss is only about 2 per cent.

Page's Weekly: 1911, December 29, page 1201.

G. H. Marx: Trans. Amer. Soc. Mech. Eng., 1912, vol. 34, page 1376.

C. W. Drake (*Electric Journal*, 1912, June, page 554) states that raw-hide may be run up to 2000 or 3000 ft. per minute.

American Society of Mechanical Engineers: "Standard Involute Gearing," 1913, September Journal, page 1405. Report of a Committee. A majority of this Committee recommended a standard system ranging from a 12-tooth pinion to a rack, the angle of obliquity to be 22½ deg. with addendum ⅓ module (0.23 pitch) and dedendum 1 module (0.318 pitch).

Burgess (*American Machinist*, 1913, vol. 36, page 113) shows the increased number of blows under a hammer test that alloy steels will sustain as compared with 0.3 per cent. carbon steel and cold-rolled steel.

Electric Railway Journal (November 8, 1913, vol. 42, page 1021). Large users of gear-wheels under severe conditions, such as tramway companies and departments, are now giving considerable attention to the wear of gear teeth under various conditions, and are keeping systematic records of measurements taken by special gear-tooth micrometers at regular intervals.

Sir C. A. Parsons states that greater attention is being given every year to accuracy in dividing or pitching out of gear wheels when being cut (Inst. Naval Arch., 1913).

Mechanical Engineer, December 19, 1913, page 577: Modern hardened and lubricated gears are said to be able to carry 3000 lb. per in. of width.

In the *Electric Railway Journal* (December 20, 1913, page 1299) are given some particulars of tests on tool-steel wheels and pinions on the Memphis Street Railway. One set had already run 183,759 miles and showed the wheel-teeth only polished and worn one-third perhaps as much as could ultimately be obtained as against a total life for soft or untreated wheels of 156,000 and pinions of 32,675 miles. (See *Science Abstracts*, B. 1914, vol. 17, page 216.)

Vincent Gartside: Trans. Manchester Assoc. of Engineers, 1912-13, page 133.

Charles Fair in reply to the Discussion (Proc. Amer. Inst. Elec. Eng., 1914, February, page 320) gives 4200 ft. per minute for cloth gears and 5000 ft. per minute for "herring-bone" teeth.

John Parker (Trans. Amer. Soc. Mech. Eng., 1913, page 785) wrote on Gearing for Machine Tools, dealing with different materials and best methods of treatment for different conditions of service.

T. V. Converse (*American Machinist*, 1914, Part 1, vol. 40, page 182) advocates increasing the angle of obliquity.

W. L. Allen ("Recent Developments in Railway Motor Gearing," *Electric Journal*, October, 1914) follows through the various materials used for railway gearing up to case-hardened steel, the cost of which is rather excessive, owing to the care necessary in the heat treatment; also describes a new process of heat treatment by which a surface corresponding to that of case-hardened steel could be obtained at a much lower cost.

H. F. Moore and F. B. Seeley: "The Failure of Materials under Repeated Stress," American Society for Testing Materials, June, 1915.

A. A. Ross: "Operating Conditions of Railway Motor Gears and Pinions," *General Electrical Review*, pages 249-258, April, 1915.

Marx and Cutter: Amer. Soc. Mech. Eng., September, 1915, "The Strength of Gear-Teeth."

APPENDIX II.

AMPLIFIED ABSTRACT FROM ARTICLE BY LASCHE IN ZEIT. DES VER DEUT. ING., 1899, VOL. 43, PAGE 1528.

In this article it is shown that the excess loads due to irregularities in pitch vary as the square of the pitch-line velocity, and may be of high values in comparison with the transmitted load.

Referring to Fig. 17, the error in the pitch of one tooth of the driven wheel is represented by the distance Δp. In consequence of this error the teeth a and b begin contact at a point X, instead of at a point Y on the theoretical line of action. Assuming that the teeth a and b remain in contact during the arc of action, and that the angular velocity of the driving wheel remains constant, it is obvious that the angular velocity of the driven wheel must vary, attaining a maximum when a and b come into contact, and gradually diminishing as b approaches the line of centres. The shaded areas 1', 2', 3', &c., on the pitch circles of the driven wheel show the movement of the latter corresponding to the uniform movements, 1, 2, 3, &c., of the driving wheel. The difference between the lengths 1' and 1 will be proportional to Δv, the difference in pitch-line velocity of the wheels when contact first takes place. This difference Δv can be ascertained for different errors in pitch and plotted against the latter for any required pair of wheels, as shown in Fig. 18.

From such a curve it is possible to read the difference in velocity Δv corresponding to any given error in the pitch, and, knowing the magnitude of Δv, the acceleration pressure P can be calculated, providing certain assumptions are made.

The following are the assumptions made:—

(1) That at the beginning of contact between the teeth a and b (Fig. 17) the driven wheel is only accelerated by one-half the difference of the pitch-line velocity Δv of the two wheels, the driving wheel being retarded by a similar amount.

(2) That the equalisation of velocity does not take place

instantaneously, but extends over a period of time corresponding to the time taken for the tooth *b* to move from the actual beginning of contact at X to the theoretical beginning of contact at Y.

Now let t = time taken to equalise the velocity; that is, time taken for tooth *b* to move from X to Y.
And let Δv = difference of pitch-line velocity at the point of contact X.
Let I = moment of inertia of largest wheel.
" M = mass of largest wheel.
" k = radius of gyration of largest wheel.
" R = radius of pitch circle of largest wheel
" $\dot{\omega}$ = angular acceleration of wheel.
Then couple necessary to produce the acceleration $\dot{\omega}$

$$= I\dot{\omega} = \frac{I \cdot \Delta v}{2 t R} = \frac{M k^2 \cdot \Delta v}{2 t R}.$$

But couple = acceleration pressure P × pitch circle radius of wheel R = P × R.

$$\therefore \quad P R = \frac{M k^2 \cdot \Delta v}{2 t R}.$$

$$\therefore \quad P = \frac{M k^2}{R^2} \times \frac{\Delta v}{2 t} \quad . \quad . \quad . \quad (1)$$

The ratio of the length 1′ in the figure to the length 1 is obviously independent of the velocity of the wheel, and simply depends upon the amount of error in the pitch and the numbers of teeth in the two gear-wheels considered. It follows, therefore, that instead of Δv we can substitute $a \times v$, where a is a constant and v is the normal pitch-line velocity of the wheels. Further, for any two given wheels with a given error in pitch, the proportion which the distance X Y bears to the circumference of the wheel will also be constant, and we may write $t = \frac{\beta}{v}$, where β is a constant and v is as above. Substituting for Δv and t in (1) we have

$$P = \frac{M k^2}{R^2} \times \frac{a}{2\beta} v^2 \quad . \quad . \quad . \quad (2)$$

which shows that, providing the assumptions made are reasonably correct, the acceleration pressure increases as the square of the velocity.

The following example taken from Lasche's paper shows the calculation of the acceleration pressure by means of formula (1). Number of teeth, 35 and 136; pitch, 1 in. (approximate); error, 0.02 in.; pitch circle diameters, 16.5 in. and 64.25 in.; height of teeth, 1 in.; horse-power, 75; pitch-line velocity, 41 ft. per second; revolutions per minute of driver, 570.

Mass of largest wheel reduced to pitch circle = $\frac{M k^2}{R^2} = 19$;

$\Delta v = 3.15$ ft. per second; $t = 0.00106$ second.

$\therefore$ Acceleration pressure $P = 19 \times \frac{3.15}{0.00212} = 28{,}200$ lb. But peripheral load due to power transmitted = $\frac{75 \times 33{,}000 \times 12}{570 \times \pi \times 16.5} =$ 1000 lb., showing that in this instance the ratio of acceleration pressure to peripheral load = 28.2.

AMERICAN IRON ORE.—About 85 per cent. of the iron ore produced in the United States is mined in the Chicago district. The output for 1914 was 32,221,897 tons, as compared with 49,070,478 tons in 1913, and 47,435,777 tons in 1912.

THE GERMAN ALKALI INDUSTRY.—The German alkali industry has fared very badly during the war. Several appeals have been made to the Legislature and the various Government departments for assistance and a rise in the officially-fixed prices; the State dues for last year were abolished in consequence. A new measure has now been introduced into the German Parliament, providing for a new and higher price-list, the foregoing of the State dues also for the current year, and the renewed postponement of new allotments until December 31, 1918. The following table shows the new prices and, for comparison, the present ones:—

	New Price. Pf.	Present Price. Pf.
Carnallite, with at least 9 per cent. and less than 12 per cent. of K_2O (in ground state)	11.0	8.5
Raw salts, with 12 to 15 per cent. K_2O (in ground state)	13.0	11.5
Manure salts, with 20 to 22 per cent. K_2O...	17.0	14.0
" " 30 to 32 " " ...	17.5	14.5
" " 40 to 42 " " ...	18.5	17.0
Chlorate of potash, with 50 to 60 per cent. K_2O	30.0	27.0
Chlorate of potash with over 60 per cent. K_2O	32.0	29 0
Sulphate of potash with over 42 per cent. K_2O	38.0	35.0
Sulphate of potash and magnesia	34.0	31.0

The new prices must not be exceeded for an increase of 1 per cent. of K_2O. The present prices were fixed by law on May 25, 1910, the prices for raw salts with 12–15 per cent. K_2O, and for manure salts with 40–42 per cent. K_2O, however, having in the meantime been raised, in September last year. The Legislature in September last took steps to assist the industry. The decrease in the sale has since then become even more serious. The home sale of alkali products in the year 1915 certainly only shows a decrease of 7.2 per cent. as compared with 1913, but the aggregate value of the sales has been very unfavourably influenced by the material decrease in the sale of the most valuable products of the alkali industry. This decrease is attributable to the reduced requirements of the German chemical industry. The export of alkali salts is almost exclusively confined to Sweden, Norway and Denmark, the Netherlands, Switzerland and the occupied districts of Belgium, France and Russian Poland. The export to other neutral countries, on account of the possibility of the goods being sold again to hostile countries, for the production of explosives, has had to be reduced to a minimum. The Kali Syndicate held a meeting on April 10 to discuss the new measure. It was stated that the proposed increase would amount to some 7,500,000 marks a year additional income, whereas the rise in the cost of labour, coal, lubricants and other materials represented an additional outlay of from 25,000,000 marks to 30,000,000 marks. It was unanimously agreed to appeal to the Legislature for an increased rise in the quotations.

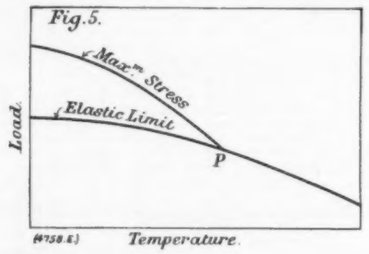
SURFACE-TENSION EFFECTS IN METALS.

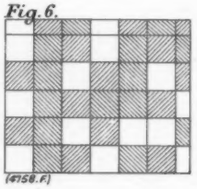
*Surface-Tension Effects in the Inter-Crystalline Cement in Metals and the Elastic Limit.**

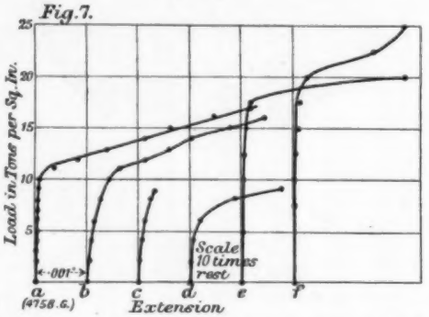
By F. C. THOMPSON, M.Met., B.Sc. (Demonstrator in Metallography in the University of Sheffield).

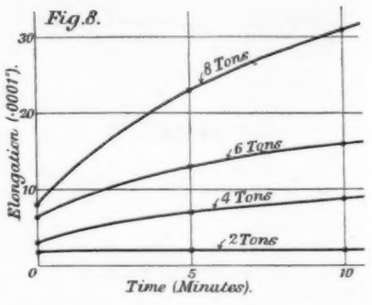
(*Concluded from Page* 514.)

Effects of Temperature on the Mechanical Properties of Metals.—The complications introduced into the study of the influence of temperature on the mechanical properties of iron, as a result of the allotropic changes, and of the marked influence of even small amounts of carbon, render it difficult to use this metal to determine how far the temperature changes in the mechanical properties to be expected from the surface-tension theory of elastic strength agree with the experimental results. A metal free from such disadvantages, such as copper, will therefore be considered. As has already been emphasised, the normal fracture of a ductile metal at room temperatures passes through the body of the crystals. At the same time the crystals are pulled out, and slipping along cleavage planes occurs. Above a certain temperature, however—720 deg. Cent. in the case of copper—the fracture changes entirely in type, and now passes through the intercrystalline regions. The crystalline matter is not appreciably deformed, the metal having become typically brittle. This remarkable change is the result of the gradual loss of strength of the inter-crystalline junctions. So long as these are stronger than the crystals, so long is the low-temperature type of fracture found. When the conditions are reversed intergranular weakness results, and the fracture passes between the crystals.









This loss of strength of the cement has been explained in a perfectly satisfactory manner by the reversion of the extremely viscous under-cooled liquid to a more mobile—and hence weaker—state. The present hypothesis, however, still affords a simple and rational explanation of these facts. The value of the surface tension decreases as the temperature rises, the crystals grow in size at the same time, i.e., n in equation (3) decreases, and Van der Waals has shown that surface films may increase in thickness as the temperature is raised, i.e., d increases. Thus every term in the equation (3) changes in such a way as to reduce the value of the elastic limit, as a result of this temperature increase. When the crystalline part of the mass has become stronger than the junctions intercrystalline fracture will occur, and the stress sufficient to overcome the cohesion of these will be sufficient to smash the specimen. Hence the maximum stress now coincides with the elastic limit. Since $\frac{2T}{d}$ is a measure of the strength of the crystalline junctions, it represents also, above the temperature at which the order of the relative strengths of these and the crystals changes, the maximum stress. Below this temperature it is a measure of the elastic limit; thus in the curve tensile strength-temperature an abrupt change should occur. This is in entire accord with the results obtained by Bengough and Hanson with copper. Fig. 5 shows the typical curve which these investigators obtained.

The interesting corollary arises from these considerations that the elastic limit curve below the inversion temperature should be a continuation of the maximum stress curve above. The paper quoted does not contain the values of the elastic limits, but if the curve above P be continued back the value of the limit at room temperature for annealed copper broken in air is 3 tons per square inch, and for hard-rolled copper 6 tons per square inch, results of approximately the right order of magnitude. For a pure metal, however, the curve will not be straight. When such a temperature is attained that the crystalline growth has an appreciable velocity, the term n of the equation (3) starts to decrease rapidly, and with it the elastic limit. This curve in the diagram will therefore bend downwards. The values of the elastic limit of copper just obtained by simple extrapolation will err notably on the high side. The curve showing the relationship of the elastic limit of copper to temperature has, however, been obtained by Huntington, and is exactly of this type.

It will thus be seen that evidence drawn from the temperature changes of the mechanical properties of metals is in excellent agreement with the facts.

Before passing to a consideration of the properties of iron and steel in the light of the theory, two further related points may be briefly dealt with.

The remarkable effect of reducing atmospheres on certain metals, *e.g.*, copper or platinum, is well known. Almost total loss of strength and intercrystalline fracture in normally ductile metals results, even when chemically no change can be detected. The solution of gases by metals in the solid state is a well-established fact, and such gases should exist chiefly in and around the amorphous modification. Such a condition may well result in a thickening of the intercrystalline films, and since the strength of the boundaries is *inversely* proportional to this dimensoin, the elastic limit must fall. If the loss of strength is such as to cause the films to become weaker than the crystalline matter, fracture in tension must pass between, instead of through, the grains. An increase of thickness of the films of 10^{-5} cm.—one two hundred and fifty thousandth of an inch—will lower the elastic limit by a half. In the case of the copper already investigated, this effect would be produced by about 2.5×10^{-8} grammes of hydrogen per cubic centimetre between the grains.

The next point of interest is the effect of intercrystalline films of extruded matter upon the mechanical strength of metals. The classical examples of such films are those first examined by Professor Arnold and J. Jefferson,[21] produced by traces of bismuth on gold and copper. The bismuth was in each case present as an intercrystalline film around the ductile crystal of perfectly unchanged gold or copper. As in the previous case, however, the material was almost devoid of tensile strength, and broke with the typical intercrystalline fracture of a metal in which the crystalline boundaries have lost their strength. If plates of two different materials are placed in a liquid which wets one only, the attraction found where the plates are both wetted is replaced by a repulsion. If a similar condition be assumed at the junctions of the grains and the cement, the pernicious effects of the latter are explained. The attraction normally present at the crystalline boundaries is absent, whence the cohesion of the mass should be, as it actually is, practically non-existent.

Application of the Theory to Iron and Steel.—The surface-tension theory of the elastic limit here outlined has been examined hitherto in connection with the properties of simple metals free from the complicating influences of allotropic transformations, or of the addition of other substances. The extension of the theory to steels is a matter of great difficulty, but its very general applicability to the simpler cases considered renders belief in its action in the less simple ones easier.

The stress-strain diagram of a normal mild steel is, as has been shown, in complete accord with the theory. Alternating stress tests also give results which are to be expected, and which can be readily explained.

We have already seen that the theory affords the explanation of the well-recognised fact that a finely crystalline metal is more dependable than a coarse one, the larger areas over which the surface-tension attractions can occur giving a corresponding higher elastic limit, on

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* Paper read before the Iron and Steel Institute, May 5.

which the dependability from the point of view of engineering construction largely depends.

In a similar fashion it is to be expected that the degree of fineness of division of the carbide of the pearlite in steel is amongst the factors capable of influencing the mechanical properties. It has been shown by Professor Arnold (22) that the influence of over-annealing on the elastic properties of steels is extremely marked. Considering a pure carbon steel of 0.9 per cent. carbon content—*i.e.*, one consisting entirely of pearlite—the elastic limit in the normal condition is approximately 24 tons per sq. in.—*i.e.*, 1 ton less than the yield point. The identical steel when annealed for 72 hours at 1000 deg. Cent. possesses a true elastic limit of only 14 tons per sq. in. (yield point less 3 tons). Now, the only micrographic change involved is in the degree of fineness of the carbide plates, and chemical change there is, so far as we know, none. Further, there is so far no reason whatever to believe that the molecular arrangement of the iron is affected. The marked loss of elasticity is therefore, on the basis of the older views, extremely difficult to explain. The theory at present under consideration, however, fits in well. Between the ferrite and the carbide plates surface-tension forces are as much to be assumed as between two crystals of iron, and formula (3) should therefore apply equally. For the same quantity of F_3C—*i.e.*, the same carbon content of the steel—the aggregation of the carbide into larger, thicker plates in the annealed steel results in a loss of area across which attractions are found. Hence the elastic limit in the annealed state, which is determined by this area of the iron-iron carbide junctions, should be, as it actually is, lower in the annealed steel than in the normal one. When this segregation of the carbide plates proceeds until the structure is essentially one of ferrite, with dot-like masses of carbide dispersed throughout, the mechanical properties should be so poor as to render the steel almost valueless, a result in entire agreement with that of practical observation.

Again, exactly the same fact is capable of offering a partial explanation of the remarkable properties of certain alloy steels. The very remarkable influence of vanadium on steel is now well known. Even when the addition does not exceed 0.2 per cent., the elevation of the elastic limit is remarkable. The yield point of such a steel containing 0.71 per cent. carbon as received from the rolls is 44 tons per sq. in.,(23) while a similar steel free from vanadium in the same condition has a limit of elasticity of only 20 tons per sq. in. (obtained from Professor Arnold's paper already mentioned). The microstructure of the vanadium steel was characterised by the fineness of division of the carbide in the pearlite, which would provide sufficient area between the two constituents to strengthen the mass to a much higher degree than would be the case in the comparatively coarse pearlite of the plain carbon steel. Since almost the whole of the metals intentionally added in practice render the microstructure of the alloy fine, both as regards the size of the individual crystals of ferrite and of the carbide plates in the pearlite, the theory would demand that, as is actually a fact, these steels should all be characterised by elastic properties far superior to those of an alloy of iron and carbon only.

Concerning the properties of steel hardened and tempered little can be said. Changes in the condition of the carbide, and, conceivably also, of the iron itself, render the problem so complex that the unravelling of a single thread is well-nigh impossible. Such observations, however, as it is possible to make are still in accord with those to be expected. Such steels are distinguished from similar ones in the normal condition by their high elastic limit, and the high ratio of this to the maximum stress. Alongside this fact is the very minute scale of the crystallisation. The hardenite formed from a plain carbon steel with 0.9 per cent. carbon heated slowly to just above the critical point $Ac_1, _2, _3$, is micrographically amorphous, but the crystallinity found in such a steel quenched from too high a temperature is justification for believing that even when the quenching temperature is only just above the critical point the mass is still crystalline, but on an ultra-microscopic scale. Such a crystallisation would present a considerable area for the interface attractions, and hence the high elastic limit is a necessary deduction from the theory.

The tempering of such a steel yields a pearlite in its maximum degree of fineness, which coexists with a yield point of about 60 tons per sq. in.

It has thus been shown that the refining action on the scale of the crystallisation of a steel resulting from the addition of other metals produces a high elastic limit, as the theory demands. It is possible, however, to explain the refining action itself from which such fundamentally important practical results accrue as a result of the fact of surface tension. When a mass is crystallising, either from fusion, or in the solid, at a critical temperature, the existence of surface tension at the boundaries tends to diminish the surface area across which it acts, or, in other words, to promote crystal growth. Now the general, though not universal, tendency of an added element, if it enters into solution, is to reduce the value of the surface tension—in other words, to render the smaller crystal less unstable. Hence the addition of an alloying element which is present in solution exerts a tendency to reduce the size of the crystal. This action, well illustrated in nickel, manganese, chromium, or tungsten steels, is, however, equally well defined in non-ferrous alloys, the addition of nickel to a 70/30 brass producing the "nickel-silvers," or the addition of manganese (even 0.25 per cent.) to these resulting in every case in a profound diminution of the crystalline size.

We may now consider in what way the mechanical properties of a steel should alter as the carbon content is increased.

Consider a plain carbon steel with x per cent. (less than 0.45 per cent.) of carbon. Then since at 0.9 per cent. of carbon the mass is composed entirely of pearlite, the fraction of the area of any plane of section composed of this constituent is $\frac{x}{0.9}$. Now across any plane of section the total resistance to yielding is the sum of the resistances due to the attractions of the ferrite to ferrite and to pearlite.

Since with a carbon content of less than 0.45 per cent. the ferrite is in excess, each grain of pearlite will be in contact with that constituent, and across any surface within the mass the area of the ferrite-pearlite interface will be $2\,\frac{x}{0.9}$ (since pearlite below will be in contact with ferrite above, and the pearlite above also in contact with ferrite below. If the black areas of Fig. 6 are pearlite below, and the shaded ones the same constituent above, the surface under consideration, it will be seen that the total ferrite-pearlite interface is twice that of the pearlite in the section).

The remaining area $1 - 2\,\frac{x}{0.9}$ will be that across which ferrite crystals adjoin each other.

Thus if T_f is the surface tension of the ferrite-ferrite boundaries, and T_{pf} the corresponding value for the pearlite-ferrite junctions,* the elastic limit of the surface will be, according to equation (2):—

$$\frac{2\,T_{pf}}{d_{pf}} \cdot \frac{2\,x}{0.9} + \frac{2\,T_f}{d_f}\left(1 - \frac{2\,x}{0.9}\right).$$

Now when the carbon content is 0.45 per cent., the volumes of ferrite and pearlite are the same, and all junctions should find the ferrite and pearlite opposed. Hence it may be assumed that $\frac{2\,T_{pf}}{a_{pf}}$ is the elastic limit of a plain carbon steel with 0.45 per cent. of carbon. The results given by Arnold show that this value is in the normal state 17 tons per sq. in. (taking the elastic limit as the yield point less 1.5 tons).

We have already seen that for pure iron in the normal state $\frac{2\,T_f}{d_f}$ is 12 tons per sq. in. Therefore the elastic strength of a plain carbon steel, whose carbon content is below 0.45 per cent., is represented by the equation:—

$$E = 17\,\frac{2\,x}{0.9} + 12\left(1 - \frac{2\,x}{0.9}\right)$$

$$= 11\,x + 12 \text{ tons per sq. in.}$$

As the carbon content rises above 0.45 per cent., being, however, still less than 0.9 per cent., ferrite-ferrite interfaces disappear, being replaced by those in which two pearlite grains adjoin. The elastic limit is now:—

$$2\,\frac{2\,T_{pf}}{d_{fp}}\,\frac{0.9 - x}{0.9} + \frac{2\,T_p}{d_p}\,\frac{2\,x - 0.9}{0.9}$$

where $\frac{2\,T_p}{d_p}$ is the elastic limit of an all-pearlite—*i.e.*, 0.9 per cent. carbon—steel. The 0.9 per cent. carbon steel of Arnold's normalised series has an elastic limit of 25 tons per sq. in.

$$\therefore E\,(0.45 - 0.9) = 2.17\,\frac{0.9 - x}{0.9} + 25\,\frac{2\,x - 0.9}{0.9}$$

$$= 9 + 18\,x \text{ tons per sq. in.}$$

Thus as the carbon is raised from 0.0 to 0.9 per cent., the elastic limit increases as a linear function of the carbon content to 0.45 per cent., and then more rapidly to the saturation point. This result is in agreement with Fig. 1 of Professor Arnold's paper already quoted. That the mechanical properties of carbon steel should alter above 0.45 per cent. carbon is a result to be expected from the microstructures. A mild steel, such as a boiler plate, is composed of a matrix of soft ferrite with hard grains of pearlite embedded in it. When, however, the semi-saturation point is passed, the structure is replaced by a hard framework of pearlite, with ferrite merely as infilling. It is to be expected that the mechanical properties of two such very different structures should be governed by different relationships.

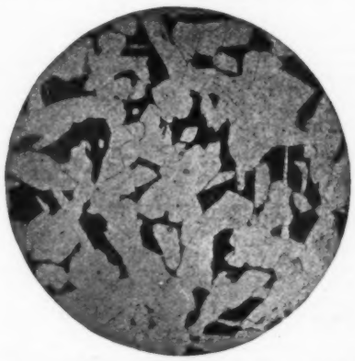

FIG. E. STEEL (AS RECEIVED). C., 0.26 PER CENT.; MN., 0.57 PER CENT. MAGNIFIED 80 DIAMETERS AND REDUCED BY ONE-TENTH.

FIG. F. STEEL (NORMALISED). C., 0.26 PER CENT.; MN., 0.57 PER CENT. MAGNIFIED 80 DIAMETERS AND REDUCED BY ONE-TENTH.

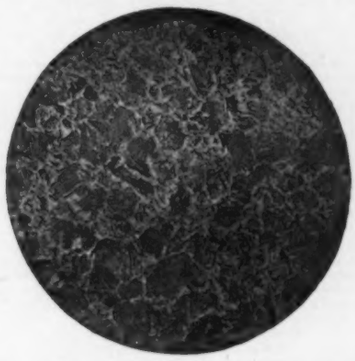

FIG. G. STEEL (QUENCHED AND TEMPERED). C., 0.26 PER CENT.; MN., 0.57 PER CENT. MAGNIFIED 80 DIAMETERS AND REDUCED BY ONE-TENTH.

Through the kindness of Professor Arnold I am allowed to record here the remarkable mechanical properties of a drastically overannealed shaft of acid open-hearth steel of the following composition:—

	Per Cent.
Combined carbon	0.26
Silicon	0.05
Manganese	0.57
Sulphur	0.043
Phosphorus	0.054
Iron (by difference)	99.02

The material endured 268 alternations under standard conditions in the Arnold alternating stress testing-machine when stressed longitudinally, and 206 when stressed transversely. Such a steel should have endured 340 + 20 alternations with the first direction. Further, the results were erratic, the highest individual test (of sixteen of which the figures recorded above are the mean) being 322, the lowest 218, both being specimens cut longitudinally. It was, however, in the tensile, and especially in the elastic, properties that the material most clearly showed its remarkable condition. A test-piece with 2 in. turned accurately to 0.564 in. diameter, when loaded normally—*i.e.*, fairly rapidly—gave the stress-strain curve *a*, Fig. 7. The true elastic limit appears to be about 10 tons per sq. in. When, however, the rate of loading was diminished and 5 minutes allowed to elapse between successive additions of 1 ton per sq. in., the curve *b*, Fig. 7, was obtained. The true elastic limit is now below 4 tons per sq. in. When a 10-minute halt was allowed at each load the curve *c*, Fig. 7, was registered. Curve *d* is that of the permanent set in the last case when the load was removed, after being maintained for 10 minutes at each load. The true elastic limit is therefore certainly not greater than 4 tons per sq. in. Fig. 8 shows the growth of the elongation with time under several loads, and clearly shows that even after 10 minutes the piece was still yielding, though at a gradually diminishing rate.

One sample of this steel was then normalised at 850 deg. Cent. and cooled in air, and a second heated to 850 deg. Cent., quenched in oil, and tempered at 350 deg. Cent. The elastic curves of these specimens are shown in Fig. 7, *e* and *f*. Clearly marked limits of elasticity are

* To speak of the surface tension of an aggregate such as pearlite is scientifically inaccurate. In the present case what is really used is a hypothetical value which is equal to the average, due to the ferrite and carbide constituents.

seen at 15 and 17 tons respectively. These treatments had entirely removed the remarkable inelasticity of the original material. The examination of these steels from the point of view at present under consideration becomes of the highest interest.

Micrographs Nos. E, F, and G show the structure, at magnifications of 80 diameters, of the steels respectively as received, normalised, and oil-quenched and tempered. The annealed and normalised specimens are specially interesting, since only comparatively small differences in the condition of the carbon will obtain. The number of crystals per centimetre length were measured as before, in each sample, and are recorded below, with the corresponding elastic limit.

TABLE V.

Condition.	Number of Crystals per Centimetre.	Elastic Limit. Tons per Sq. In.	Thickness of Film $\times 10^{-6}$ Centimetres.
Drastically annealed... ...	168	4.0	4.46
Normalised	416	15.0	1.16
Oil-quenched and tempered	500 (?)	17.5	1.06

The elastic limit is an almost perfectly direct function of the number of crystals per centimetre. For pure metals the elastic limit is proportional only to the one-third power of the number of crystals per unit length (equation 3). The influence of the degree of fineness of the pearlite in a steel, in addition to the size of each crystal of iron or grain of pearlite, will further increase the dependence of the elastic limit of a steel on the micrographic size, whence the greater dependence of the elastic limit on n is to be expected. Using equation (2) to obtain, at any rate, an approximation to the thickness of the films in the different samples, we obtain the values recorded in Table V. The values for the normalised and quenched steels are practically identical with those for pure iron and for nickel. The films in the drastically annealed steel possess, however, a thickness very much greater. This increase in the thickness of the film as the rapidity of the cooling decreases has already been noticed in the samples of pure iron. This would probably not be expected, but rather a *thinner* film of non-crystalline metal.

During the recrystallisation of the iron, however, at a sudden critical point with a normal rate of cooling, the velocity of the recrystallisation must be rather great, the crystals growing very rapidly from a series of centres. Under these circumstances it is not improbable that the tendency will be for each crystallisation to overshoot its normal limits before being restrained by the influence of adjacent ones. Thus in normally and quickly cooled materials the films may be thinner than correspond to a condition of equilibrium. A more or less prolonged reheating, however, at temperatures just below that at which the recrystallisation occurs will subsequently allow the conditions of the quickly cooled metal to pass into the more stable state, and in time, for the process may be expected to be a slow one, molecules leave the space-lattices at the boundaries, reverting to the amorphous arrangement. A subsequent normalising, *i.e.*, a reheating just above the upper critical point, by breaking up the whole structure, combined with more or less rapid cooling, will cause a reversion of the films, and hence of the properties, to the normal type.

The mechanical properties of the steel as received, normalised, and oil-quenched and tempered are recorded in Table VI.

TABLE VI.

Condition.	True Elastic Limit. Tons per Sq. In.	Yield Point. Tons per Sq. In.	Maximum Stress. Tons per Sq. In.	Elongation per Cent. on 2 in.	Reduction of Area per Cent.	Brinell Hardness (3000 Kilogrammes).
Drastically annealed ...	4.0	13.0(?)	27.4	35.6	60.0	94
Normalised	15.0	17.5	30.8	31.0	58.4	94
Oil-quenched and tempered	17.5	22.5	35.6	26.0	61.0	121

The maximum stresses and Brinell hardness numbers (taken with a 10-mm. ball and pressure of 3000 kilogs.) of the annealed and normalised steel are of interest on account of their great similarity in the two samples. If, as has already been suggested (*vide infra*), the hardness of a metal depends chiefly on the intrinsic pressure—*i.e.*, on the crystals themselves—this result is to be expected. It is exceedingly difficult to see how such a process as annealing can affect the crystalline arrangement of the grains. Apart from critical points, soaking and slow or quick cooling could hardly affect the crystallisation at all. Traube has shown, and other results on the present paper have confirmed his conclusions, that the hardness of a metal is determined by the intrinsic pressure of the crystals. Hence, since the hardness of the annealed and normalised steels are coincident, we are justified in assuming that the crystallinity in the two cases is, as would certainly be expected, identical. It is evident, therefore, that the elastic limit of the metal does not depend primarily on the crystals, since this value is 4 tons per sq. in. in one case and 15 tons in the other. If the elastic limit is not chiefly dependent on the crystalline masses themselves, it must, as the present theory demands, be chiefly determined by the *intercrystalline* boundaries.

It can thus be stated with a fair degree of confidence that the factors which primarily govern the tensile strength of a metal and its elastic limit are not the same. The maximum stress depends chiefly on the crystals themselves, the elastic limit being determined by the nature and extent of the inter-crystalline junctions. A certain degree of parallelism of the two properties is, however, to be expected, since, as has already been seen, the intrinsic pressure of the crystals and the surface tension run side by side.

If the basis hypothesis of an intercrystalline cement around the crystal grains be true, and if, for any reason, the thickness of the films in a sample be increased, it is to be expected that Young's modulus will alter. The extension under strain, being the sum of the elastic extension of the crystalline material and of that due to the viscous flow of the cement, will alter according to the relative proportions of the two constituents. Whether an increase in the amount of the cement will increase or decrease Young's modulus for that material can only be determined by experiment; but if the assumptions are correct, it should change with changing quantities of the non-crystalline material.

By multiplying the number of crystals per unit length by the thickness of each film, an approximation to the *quantity* of the amorphous modification present is obtained. This has been done for the samples of iron and steel in Table VII.

TABLE VII.

Material.	Condition.	No. of Crystals per Cm. (n).	Thickness of Film (d).	$n \times d$.
Steel	Annealed	168	4.46×10^{-6}	7.5×10^{-4}
	Normalised	414	1.16×10^{-6}	4.8×10^{-4}
	Quenched and tempered	500	1.06×10^{-6}	5.1×10^{-4}
Iron	Annealed	276	1.83×10^{-6}	5.1×10^{-4}
	Normalised	343	1.45×10^{-6}	5.0×10^{-4}
	Quenched and tempered	690	1.25×10^{-6}	8.6×10^{-4}

The value of Young's modulus for both the normalised and quenched and tempered steels is about 32,000,000 lb. per sq. in., and these contain about the same quantity of the amorphous variety. For the drastically annealed sample, which, if the measurement of the thickness of the films made here be correct, contain 50 per cent. more of the amorphous material, Young's modulus is 38,000,000 lb. per sq. in.

SUMMARY.

1. The idea previously put forward by several workers that surface-tension forces act within the amorphous modification between the crystalline grains in a metal is adopted and utilised to give a measure of the elastic limit.

2. The theory affords an explanation of the elastic limit, yield point, and the chief effects of strain, both static and dynamic, on metals.

3. By the aid of the relationship $E = \frac{2T}{d}$, where E is the elastic limit, and T the surface tension of the non-crystalline material, a measure of the thickness of the films d in several metals can be obtained.

4. The loss of strength of a metal such as copper (free from the complicating influence of allotropy) as the temperature is raised receives a ready explanation in terms of the theory.

5. The increased elastic limit of alloy steels compared with a plain carbon steel, and of steel with a fine structure compared with the corresponding coarser material, is in accord with the theory's demands. The change of strength of steel with the carbon content can be foretold and is in accord also with practical observation.

6. The conditions governing the tensile strength or hardness of a material and its elastic limit, though running parallel, are yet distinct. The hardness is due chiefly to the composition of the crystalline part, the elastic limit depending on the intercrystalline boundaries.

To Professor J. O. Arnold the author is in the highest degree grateful for permission to use the results on the annealed shaft made for him, and for facilities, advice, and suggestions throughout the whole course of the work. The most sincere thanks of the author are due to Sir Robert Hadfield, at whose suggestion this paper was prepared, for his constant encouragement, and to his assistant, Mr. Main, for the proof of equation (2).

BIBLIOGRAPHY.

1. Thompson, F. C. Transactions of the Faraday Society, 1915, vol. ii., page 104.
2. Beilby, G. T. Philosophical Magazine, 1904, Series VI., vol. viii., p. 258; Journal of the Institute of Metals, 1911, No. 2, page 5.
3. Rosenhain, W. British Association, September Meeting, 1913; ENGINEERING, 1913, October 17, page 537.
4. Desch, C. H. Journal of the Institute of Metals, 1914, No. 1, page 57.
5. Brillouin. Annales de Chimie et de Physique, 1898, vol. xiii., page 377.
6. Curie, P. Bulletin de la Société française de Minéralogie, 1885, vol. viii., page 145.
7. Tammann, G. Lehrbuch der Metallographie, pages 20–23 and 75–78.
8. Fearnsides, W. G. Transactions of the Surveyors' Institute, 1913, page 33.
9. Rosenhain, W., and D. Ewen. Journal of the Institute of Metals, 1912, No. 2, page 149.
10. Dalby, W. E. Proceedings of the Royal Society, 1912, Series A., vol. lxxxvi., page 414, and 1913, vol. lxxxviii., page 281.
11. Hook. Sitzungaberichte der k.k. Akademie der Wissenschaften, Wien, 1899–IIa., vol. cviii., page 1516.
12. Thorpe and Rücker. Transactions of the Chemical Society, 1884, vol. xlv., page 135.
13. Smith, S. W. Journal of the Institute of Metals, 1914, No. 2, page 168.
14. Pascal and Journiaux. Comptes Rendus, vol. clviii., page 414.
15. Goerens, P. Iron and Steel Institute: Carnegie Scholarship Memoirs, 1911, vol. iii., page 320.
16. Rosenhain, W. Journal of the Iron and Steel Institute, 1904, No. 1, page 360.
17. Traube. Zeitschrift fur Anorganische Chemie, 1903, vol. xxxiv., page 413.
18. Arnold, J. O. Journal of the Institution of Naval Architects, 1908, vol. l., page 260.
19. Ewing, J. A., and J. C. W. Humfrey. Philosophical Transactions, A., 1902, vol. cc.
20. Thompson, F. C. Philosophical Magazine, 1916.
21. Arnold, J. O., and J. Jefferson. ENGINEERING, 1896, vol. lxi., page 176.
22. Arnold, J. O. Proceedings of the Institution of Civil Engineers, 1895, vol. cxxiii., page 127.
23. McWilliam, A., and E. J. Barnes. Journal of the Iron and Steel Institute, 1911, No. I., page 294.

COLONIAL AND FOREIGN ENGINEERING PROJECTS.

WE give below a few data on several colonial and foreign engineering projects, taken from the *Board of Trade Journal*. Further information on these projects can be obtained from the Commercial Intelligence Branch, Board of Trade, 73, Basinghall-street, London, E.C.

Australia.—The State Rivers and Water-Supply Commission has approved of a water-supply scheme for Frankston, Mornington, Flinders naval base, and other places in the Mornington Peninsula (Victoria) from the Bunyip River. The cost of the undertaking is estimated at between 100,000*l.* and 170,000*l.*

Portugal.—The *Diario do Governo*, Lisbon, publishes the text of a Bill, presented to the Portuguese Senate, to authorise the Municipality of the Isle of Santo Antão to raise a loan to the amount of 50,000 escudos (about 7100*l.* at current rate of exchange) to be devoted to the construction of irrigation canals for agricultural purposes.

Italy.—The *Gazzetta Ufficiale*, Rome, publishes a Law granting a concession to the Municipality of Rome for the construction and working of a normal-gauge electric railway from the Piazza Venezia to Ostia Nuova. The same journal contains a further Law authorising the completion of the Aulla to Lucca railway, comprising the construction of the sections Castlenuovo di Garfagnana—Piazza al Serchio; Piazza al Serchio—Minucciano; Minucciano—Molino d'Aiola; and Molino d'Aiola—Monzone.

Argentina.—The *Boletin Oficial*, Buenos Aires, publishes a Decree authorising the Argentine Sanitation Works Department to allot the sum of 50,000 pesos currency (about 4380*l.*) for the survey and preparation of a scheme for the installation of a sewerage system in the town of Mendoza.

Republic of Colombia.—The *Diario Oficial*, Bogotá, publishes a Decree reconstituting the Commission appointed to survey the projected Cucuta-Rio Magdalena Railway, dividing it into two sections, with three engineers in each, under the direction of the chief engineer. One of these sections will continue the survey of the route from Ocaña to Puerto Araujo, and the other will study the route from Ocaña to the Rio Magdalena. Both of the surveys are to be completed, if possible, before December 31 next.

THE CANADA YEAR-BOOK, 1914.—This year-book has recently been issued. It is published by authority of the Hon. Sir George E. Foster, K.C.M.G., M.P., Minister of Trade and Commerce. The price is one dollar. It gives a map of Canada and deals in detail with the Constitution and Government of the Dominion; its physical characteristics; area and population; production; trade and commerce; transportation; finance, &c. The book measures 9 in. by 6½ in., and contains close upon 700 pages of data and statistics, reference to which is facilitated by an excellent index.

STEAM SAFETY VALVES.—In a paper recently read before the American Society of Mechanical Engineers, Mr. G. H. Clark states that some difficulty is being met with in providing sufficient safety valve area for modern boilers. The old rules, based on the amount of heating surface or on the grate area, are now inadequate in view of the way in which modern water-tube boilers can be forced. A boiler rated at 500 horse-power is, in fact, capable of generating 45,000 lb. of steam per hour. Such a boiler is, he says, commonly fitted with three 4-in. safety valves—viz., two on the drum and another on the pipe leading from the superheater. With the maxmium lift allowed by the regulations, each valve (under 200 lb. pressure) has a discharging capacity of 9420 lb. per hour, so that to be capable of passing the whole of the steam generated five valves would be required instead of three. Again, a Stirling boiler has been built rated at 2356 horse-power, but actually capable of producing 148,000 lb. of steam per hour. The largest valves permitted are 4½ in. in diameter, and with the limit of lift allowed eleven valves would be required to pass the quantity stated, taking the working pressure at 200 lb. gauge.

"ENGINEERING" ILLUSTRATED PATENT RECORD.

SELECTED ABSTRACTS OF RECENT PUBLISHED SPECIFICATIONS UNDER THE ACT OF 1907.

The number of views given in the Specification Drawings is stated in each case; where none is mentioned the Specification is not illustrated.

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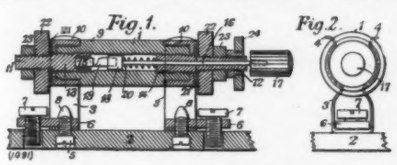
The date of the advertisement of the acceptance of a Complete Specification is, in each case, given after the abstract, unless the Patent has been sealed, when the word "Sealed" is appended.

Any person may, at any time within two months from the date of the advertisement of the acceptance of a Complete Specification, give notice at the Patent Office of opposition to the grant of a Patent on any of the grounds mentioned in the Act.

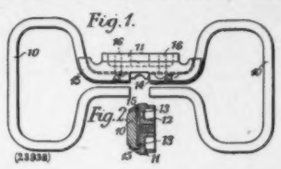
ELECTRICAL APPARATUS.

1091/15. Sterling Telephone and Electric Company, Limited, and T. D. Ward-Miller, London. Wireless Signalling. [5 *Figs.*] January 22, 1915.—This invention relates to detectors, such as are employed for wireless telegraphy, constructed in cartridge form. The object of the invention is to provide for withdrawing the members of the contact from one another for purposes of transport and so forth, to avoid any possibility of damage in transit, while at the same time retaining the feature that the position of contact between the two contact members can be varied as desired. In accordance with the present invention, one of the elements forming the detector contact is normally, when in use, spring-pressed against the other element, but can be withdrawn against the spring pressure by means of an external handle, and is also provided with means for retaining it in the withdrawn position for purposes of transport and so forth. A single cartridge-detector 1 is shown in connection with contacts upon an ebonite base 2. It is obvious that any number of such detectors may be mounted upon a single base side by side. The holders for the cartridges each consist of a pair of spring-clips 3 upstanding from the base 2, ending at the top in splayed arms 4 for the purpose of embracing the ends of the cartridge. The clips are secured to the base by screws 5, which also screw through contact-bars 6 and hold these latter in place. The bars 6 are provided with screws 7, which are merely terminals. The arms 3 are stamped as shown in Fig. 1 at 8, with the object of slightly stiffening the springs. The cartridges each consist in the main of a cylindrical protecting-case 9 of ebonite or other suitable insulating material. Upon each end of the cylindrical case 9 a metal sleeve or cap 10 is provided, and it is this cap which is embraced by the spring-arms and forms the terminal of the cartridge-detector. In the drawing the cap is shown secured to the ebonite by means of a screw-thread, but small pins may be employed for



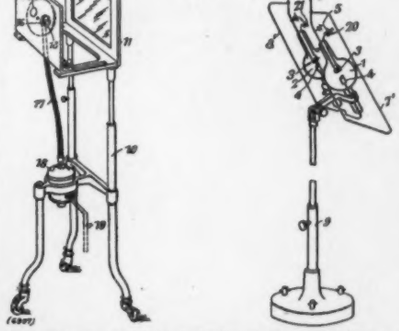
ensuring that the caps do not become loose. Metal plugs 11, 12 pass through the centres of the caps 10. Each of these plugs is of a smaller diameter at its outer end, but is screw-threaded throughout its length. The larger screw-threaded portions 13, 14 screw into the inside of the ebonite casing. The left-hand plug 11 is recessed at its inner end, as shown, to form a cup which receives the detector material, which may be in the form of a crystal 15 cast into the cup in well-known manner. The right-hand plug 12 is centrally bored throughout its whole length. A metal pin 16 passes completely through the bore of this plug, and on its outer end carries an insulating handle 17. At the other end it extends into the insulating casing 1, and at its extreme end carries a metal cup 18, which carries the detector material 19, which co-acts with the material 15. This may again be a crystal, and is preferably pointed, or, instead, may be a metal point. Preferably it is so mounted that the point is eccentric to the pin 16, so that, on rotating the handle 17, the point of contact between the detector point and the surface of the crystal 15 varies. A helical spring 20 surrounds the pin 16, and is in a state of compression between the cup 18 and the inner end 14 of the plug 12, and thus serves to keep the detector point 19 in contact with the surface of the crystal 15. The smaller end of each plug projecting from the insulating casing 1 receives first of all a thin washer 21, and next a nut 22 of ebonite or other suitable material, and then a metal clamping-nut 23. On the right-hand plug, however, there is a further nut 24, of ebonite with a metal bush. The action of this last nut is as follows:—When screwed home, as shown in Fig. 1, the detector point 19 is in contact with the surface of the crystal 15; but if the nut 24 be screwed outwards, it comes into contact with the handle 17, and if the unscrewing be persisted in, pushes the handle 17, the pin 16, and the cup 18 outwards. Hence it withdraws the detector point 19 while compressing the spiral spring 20. (*Accepted January* 19, 1916.)

23,938/14. The British Thomson-Houston Company, Limited, London (*General Electric Company, Schenectady, U.S.A.*). **Electric Meters.** [9 *Figs.*] December 11, 1914. This invention relates to electric meters, and more particularly to attaching shoes for the permanent magnets thereof. According to this invention, the method of securing a supporting member to a permanent magnet consists in forcing the supporting member into intimate contact with the magnet under considerable pressure, and maintaining the state of stress between the magnet and the supporting member occasioned by such pressure for an appreciable length of time. Fig. 1 illustrates a pair of permanent magnets 10 secured to a shoe 11, in accordance with the principle of this invention. The permanent magnets 10 are of a well-known design employed in electric motor meters for damping the rotation of the movable element. The magnets are adapted to be securely fastened to the shoe 11 in accordance with the principle of this invention. The shoe 11 is cast of composition metal, which, as is well known, is considerably softer than the hardened steel of the magnets. In accordance with the present invention, that portion of each permanent magnet to which the shoe is attached is of substantially trapezoidal cross-section. This will be clearly seen by reference to Fig. 2 of the drawings, wherein the magnet 10 is represented as having a substantially quadrilateral cross-section with two sides substantially parallel and the other two sides non-parallel and converging towards each other. The shoe has a base portion 12, which is adjacent the longer of the two parallel sides of the magnet, and which is provided with projections 13 in engagement with this side of the magnet. It will be observed that the projections 13 are the only part of the base portion 12 of the shoe in actual contact with the magnet, and that the remainder of the base portion extends substantially parallel to the longer of the two parallel sides of the magnet, but is separated therefrom by a narrow air space. The shoe is cast of composition metal, and is secured to the magnet in its cast condition without any previous machining. Since it is substantially impracticable to cast the shoe so that the base portion 12 has a perfectly plane surface, it is necessary to provide the projections 13, which form four points of support for each magnet and serve to satisfactorily position the magnet with respect to the shoe, regardless of any irregularities upon the adjacent surfaces of these two members. The base portion 12 of the shoe is provided with a



central boss 14, which determines the minimum distance between the two magnets 10. The shoe 11 has integrally attached thereto two pairs of lugs 15, each pair of lugs being adapted to firmly secure one of the permanent magnets 10 to the shoe. It will be observed that the lugs 15 are designed to engage with the two non-parallel sides of the magnet. In shoeing the magnet, the magnet is first placed in its proper position with respect to the shoe. The magnet and shoe thus assembled are placed in a power press, and the press is then operated to squeeze or force the lugs 15 into very intimate contact with the non-parallel side of the magnet under a pressure of several tons per square inch. (*Sealed.*)

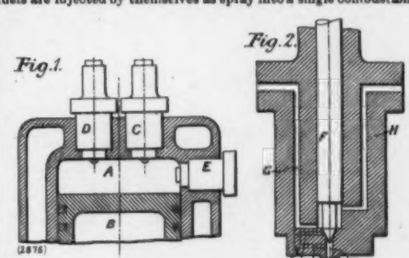
6807/15. The British Thomson-Houston Company, Limited, London (*General Electric Company, Schenectady, U.S.A.*). **X-Ray Apparatus.** [1 *Fig.*] May 6, 1915.—The present invention relates to apparatus for viewing objects by means of X-rays, whereby shadow images in stereoscopic relief are produced. In such apparatus a pair of X-ray tubes or two pairs of electrodes in a single tube are alternately subjected to current impulses in the proper direction to produce X rays, and the images are viewed in rapid succession, first by one eye and then by the other, through apertures opened by a synchronously-operated rotary shutter, so that, owing to the persistence of vision, the images blend, and are seen in stereoscopic relief. A necessary feature of such apparatus hitherto has been contact-making or commutating devices for producing current impulses in the proper direction. According to this invention, X-ray tubes of unidirectional conductivity are employed, so that the electrodes may be directly, and, during operation, permanently connected to a source of alternating current, the cathode of one pair of electrodes and the anode of the other pair being directly connected to one terminal of the source, and the other two electrodes—anode of one pair and cathode of the other respectively—being directly connected to the other terminal of the source. The Röntgen tubes 1, 2 are of the rectifying or unidirectional conductivity type. These tubes each have a cathode 3 comprising a refractory material, such as tungsten, adapted to be heated to incandescence. The cathode is preferably of filamentary form, and, as indicated, is surrounded by a conductive ring connected to the cathode, whereby the static field near the cathode is caused to radially direct or focus the electron discharge emanating from the cathode upon an anode 4, also preferably consisting of tungsten. The space within the tube is evacuated to such



a low pressure, and the electrodes are so completely freed from gas, that electrical conduction through the tube occurs as a substantially pure electron discharge, and evidences of positive ionisation are substantially absent during the operation of the tube. When the cathode is heated to incandescence, for example, by means of a battery 5, and a sufficiently high potential is impressed between the cathode and anode, and with the anode at a temperature not above dull redness, passage of current can occur only when the heated electrode is negative. Because of this asymmetric characteristic the tubes 1 and 2 therefore may be connected in such a manner to an alternating source of current, for example, the secondary of a transformer 6, that one half wave will pass through tube 1, and the other half wave will pass through tube 2. In the connections illustrated, the cathode of tube 1 and anode of tube 2 are connected by conductors 7 and 71 to one terminal of the transformer secondary, and the cathode of tube 2 and the anode of tube 1 are connected by conductors 8 and 81 to the opposite terminal of the transformer secondary. For stereoscopic X-ray examinations the two tubes may be supported by an adjustable stand 9. Opposite the tubes is located an adjustable tripod 10, carrying a fluorescent screen 11 and a shield 12, in which are located two sight-holes 13, 14, spaced apart a suitable distance so that one eye of the observer can be placed to one sight-hole and the other eye to the other sight-hole, to observe images on the screen 11. A shutter 15 (shown in dotted lines) is located to revolve between the two sight-holes in synchronism with the alternations of the electrical current supplying the X-ray tubes. A hole 16 in the shutter 15 is positioned to uncover the sight-hole 13 when the tube 2 is receiving current, and to uncover the sight-hole 14 when the tube 1 is receiving current. The desired synchronous operation of the shutter can be conveniently secured by a flexible shaft 17 driven by a synchronous motor 18. This motor preferably is connected by the conductor 19 to the source of current whereby the transformer 6 is supplied. When an object to be observed by means of the X-ray tubes is placed between the screen 11 and the two X-ray tubes, and the shutter is rotated in synchronism with the current impulses in the tubes, as above described, a succession of images upon the screen 11 may be observed. The alternations of the current are so chosen that the succession of images will blend by persistence of vision to produce upon the observer the effect of a continuous shadow image in stereoscopic relief. The current taken by the tubes 1 and 2 may be regulated by adjusting the filament temperatures by means of the variable resistances 20, 21, to be substantially the same, and this adjustment of current will remain invariable. The tubes 1, 2 when taking the same current and operating from a common source will give rays of substantially equal intensity. The hardness may be varied at will by changing the transformer voltage. It will be observed that this arrangement possesses the advantage of extreme simplicity, as no complicated circuit-closing apparatus is required to energise the X-ray tubes during the desired time intervals. The synchronism between the revolution of the shutter and the like successive illumination of each of the tubes is necessarily rigidly maintained, as the shutter may be operated by the same source of alternating current that is impressed upon the X-ray tubes. (*Sealed.*)

GAS-ENGINES, PRODUCERS, HOLDERS, &c.

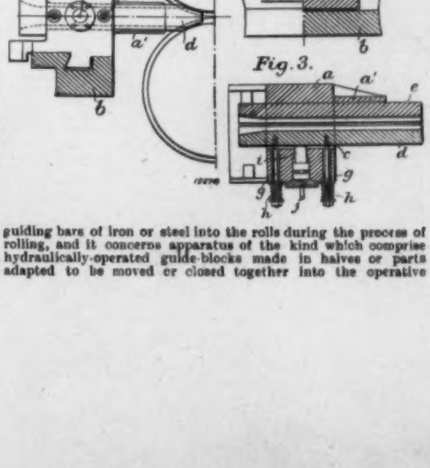
2876/15. Sir K. I. Crossley, Manchester, and W. L. Webb, Hale. Internal-Combustion Engines. [2 *Figs.*] February 23, 1915.—This invention relates to the kind of internal-combustion oil-engines of either the two-stroke or four stroke type in which the oil fuel is injected as spray under pressure from a pump, accumulator or the like, at or near the end of the compression stroke, into the air compressed into the combustion-chamber without the assistance of compressed gas or air, and in which engines the heat produced by the compression of the air charge in the cylinder may be or may not be sufficient to effect ignition. The object of the invention is to enable engines of the kind described to be operated by means of tar-oil or of alcohol or of any liquid fuel having either a high specific gravity or/and a high ignition point. The ignition of such oils presents difficulty owing either to the use of a very high-compression pressure, or to the use of a vaporiser or igniter. According to this invention, the engine is provided with either two separate fuel injectors or sprayers, one for power oil and one for ignition oil, and arranged either in one or two separate housings, or with a single fuel-injector or sprayer in the housing of which are arranged separate ports for the two fuels. In either case the fuels are injected by themselves as spray into a single combustion-



chamber by means of pumps, accumulators or the like. Referring to the drawing, Fig. 1 shows a combustion-chamber A and piston B of an engine of the kind described, and provided with ignition-oil and power-oil injector housings C and D. An ignition device, if one is used, may be arranged at E. It will be noted that in this illustration the ignition-oil injector and power-oil injector are contained in separate housings, but, as before stated, they may both be contained, if desired, in a single housing. In Fig. 2 a single oil-injector or sprayer is shown in section, and is provided with a single delivery-valve F of the loaded piston-valve type (loaded by means of a spring or other means, not shown). This valve is lifted off its seat by pressure of the oil from a pump, accumulator or the like. The ignition oil enters the housing by the port G, and the power oil by the port H. The ignition oil-port may terminate just behind the seating of the delivery-valve, as shown, or at the seating itself, as shown in dotted lines at K, or it may emerge, as shown by dotted lines at L, into the delivery port M, between the delivery-valve seating and the spray-orifice or orifices N, or, if preferred, it may emerge directly into the combustion-chamber through an orifice such as that shown by dotted lines at P. (*Sealed.*)

MINING, METALLURGY, & METAL WORKING.

2270/15. G. Jones and T. R. Spencer, Middlesbrough-on-Tees, and Dorman, Long and Co., Limited, Port Clarence. Rolling-Mill Guide-Box. [3 *Figs.*] February 12, 1915.—This invention relates to an apparatus for

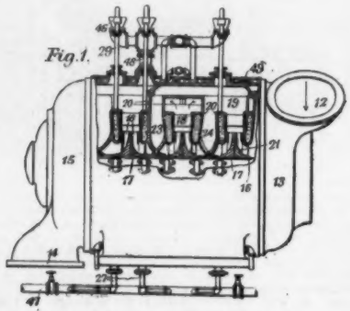


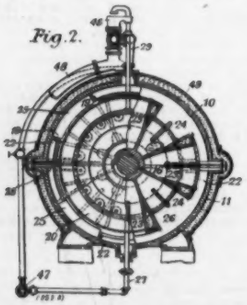
guiding bars of iron or steel into the rolls during the process of rolling, and it concerns apparatus of the kind which comprise hydraulically-operated guide-blocks made in halves or parts adapted to be moved or closed together into the operative

guiding position under the action of hydraulic pressure. The object of the present invention is to provide simple and efficient apparatus for the purpose mentioned. According to this invention, a guide-block is employed having a divided guide, whereof either or each part is moved towards the other by means of an hydraulic piston directly pressing on the back thereof. In carrying out the invention, a guide-block *a* of any suitable form and means of attachment to the guide-rest *b* is made with a slot *c*, in which two half-guides *d* and *e* may be adjusted sideways to any position, but end movement towards the rolls is prevented by a flange *f* at the in-going end. One of the half-guides *e* may be not movable, but supported, as shown in Fig. 3, by an extension a^1 of the guide-block. The movable part *d* of the guide is fitted with one or more bolts *g* which pass through holes in the guide-block, and springs *h* pressing on the nuts cause the movable part *d* of the guide to be pulled away from the fixed part *e* of the guide. A cylinder is formed in the block *a*, fitted with a plunger *i*, made tight for fluid pressure by any suitable means, the end of the plunger projecting through the block into the slot *c* and pressing on the back of the movable part *d* of the guide. This hydraulic cylinder, with its cover securely jointed and connected to an operating valve of any suitable type by a pipe *j*, may be integral with the guide-block, or it may be a separate cylinder properly secured to the block, so that the piston presses direct on the back of the guide to be moved. The workman can operate by a handle in any convenient position the valve admitting or exhausting the fluid pressure to and from the cylinder, thus causing the plunger *i* to overcome the resistance of the springs *h*, and close the movable part *d* of the guide upon the bar being rolled. (*Sealed.*)

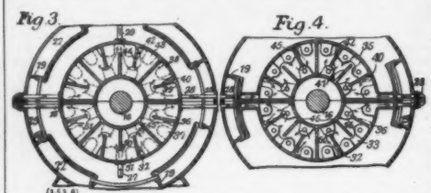
PUMPS.

353/15. The British Thomson-Houston Company, Limited, London (*General Electric Company, Schenectady, U.S.A.*). **Centrifugal Compressors.** [7 *Figs.*] January 8, 1915.—This invention relates to centrifugal air-compressors, especially of the multi-stage type, and its object is to provide an efficient cooling system therefor, in order to abstract the heat arising from the compression of the air and the friction of the same against the walls of the curved passages through which it flows. The invention consists in a diaphragm for a multi-stage centrifugal compressor, comprising upper and lower halves having two hollow walls divided by staggered radial partitions into compartments, all of which contain baffle-plates, cross-passages connecting one wall with the other, the partitions, baffle-plates, and cross-passages being so arranged that the cooling medium flows in two streams in a tortuous course through successive compartments in the two walls alternately. The casing of the machine is composed of an upper half 10 and a lower half 11, meeting on a horizontal axial plane. The intake 12 for the air is located in the head 13 of the casing, the outlet 14 being in the head 15. The halves of the casing and the heads are suitably flanged and secured together by bolts. The lower half has feet which are supported by a a suitable bed-plate or other foundation. In the heads of the casing are bearings in which are journalled the shaft 16, on which are mounted any desired number of impellers 17. The drawings show a three-stage





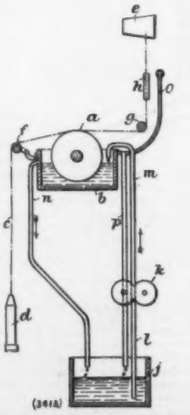
machine having three impellers, each of which has a central body, with blades 18 cast into it on both sides. The air or other fluid enters each set of blades in an axial direction, but it is thrown off from the periphery of the impeller in a radial direction, its velocity being altered to pressure in suitable stationary discharge passages. The impellers act successively upon the fluid, which is forced from one to another through passages in the diaphragms which separate the chambers in which the impellers work. The degree of compression to which the fluid is subjected depends upon the number and size of the impellers and the speed at which they are rotated. In order to cool the compressed air, water or other heat absorbing medium is circulated through the machine in proximity to the air-passages. The interior of the casing has a plurality of inwardly extending longitudinal radial ribs 19, whose edges are bored out cylindrically to fit the pheripheries of the circular diaphragms 20. The air entering through the intake 12 divides into two portions, one of which goes directly to the right-hand side of the first (right hand) impeller in Fig. 1, through the central eye 21, while the other portion divides into four parallel streams, which flow through the spaces 22 between the ribs 19, passing around the edge of the diaphragm to the radial passages 23 therein, which conduct it to the left-hand side of the first impeller. The air thrown off by this impeller passes to the left, part of it dividing through the radial passages 24 (which alternate with the passages 23) to the right-hand side of the next impeller, while the remainder flows through longitudinal spaces 25 (alternating with the spaces 22) to the left-hand side of the next impeller by way of radial passages in the next diaphragm. The walls of each diaphragm are hollow and the chamber in each wall is divided in two horizontally, because the diaphragm is made in upper and lower halves, to facilitate assembling and repairs. At four points the right and left chambers in each half communicate through passages formed in the partitions 26 between the radial passages 23, 24, the outer portions of said partitions being doubled-walled for that purpose (Fig. 2). Each of the chambers in the hollow walls of the diaphragm is divided into compartments by means of staggered partitions 50 and 51, and each compartment has one or more baffle-plates. Coming through a pipe 27, the water enters a compartment in the left-hand lower chamber of the diaphragm (as seen in Fig. 3). This chamber is shown in section in Fig. 4, and it will be seen by following the arrows that the water divides into two parts, one flowing to the right, and the other to the left, and both passing in a serpentine course, first through the two lower chambers and then through the pipes 28 connecting the lower chambers with the upper chambers, and then through the two upper chambers until it leaves by the pipe 29. Tracing the path of the right-hand water stream in Fig. 4, it is seen to pass over the edge of the baffle 30 in compartment 31, left wall, then through a cross-passage 32 in a partition 26 to the right-hand compartment 33 in the lower chamber of the right wall of the diaphragm; then over and under the edges of the staggered baffles 34, then in part through a pipe 28 to the compartment 35 in the upper chamber of the right wall, and in part through a cross-passage 36 to the com-



partment 37 in the left wall; thence through a pipe 28 to the compartment 38 in the upper chamber of that wall. Passing around the baffle 39 in the compartment 38 the water goes through a cross-passage 40 in the compartment 35 in the right wall, where it dodges around the staggered baffles 41 to the cross-passage 42, by which it returns to the left wall, entering compartment 43 from which, after rounding the baffle 44, it escapes by the pipe 29. The course of the other half of the water around the left-hand side is identical with that just described, the two portions meeting in the compartment 43. It will thus be seen that the cooling medium passes from a compartment in one wall across to a compartment in the other wall, thence back to the next compartment in the first wall, and so on, flowing through successive compartments in the two walls alternately. The cooling water contains more or less air, which is liable to collect in upper corners in the compartments and prevent the water from coming in contact with the heated metal. Vent-holes 45 are provided in the partitions and baffles at points where the air or cooling medium is likely to pocket, so that the air can escape and be carried away by the circulating water, which can thus reach all nooks and corners of the chambers. The heated water, escaping through the pipe 29, flows into an open funnel 46, thus enabling the attendant to see at a glance whether each diaphragm is getting the proper quantity of cooling water and whether any undue heating is occurring. The several diaphragms are connected in multiple to the water-pipe 47, and the several funnels deliver the water to a common waste-pipe 48. The entire casing may be surrounded by a jacket 49, forming an enclosing space, through which cooling water can be circulated. (*Sealed.*)

TEXTILE MACHINERY.

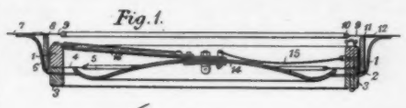
3415/15. C. C. Coffey, Bradford, and R. S. Jennigs, Steeton. Moistening Yarn. [1 *Fig.*] March 3, 1915.—The present invention relates to improvements in and relating to the moistening of spun yarn during winding and similar processes, and has for its object an improved arrangement of parts for ensuring a constant amount of moisture being imparted to the yarn by maintaining the water-level constant in the usual trough in which the roller over which the yarn passes is located. According to this invention, the usual trough is connected up to the tank containing water and to a pump in such a way that water

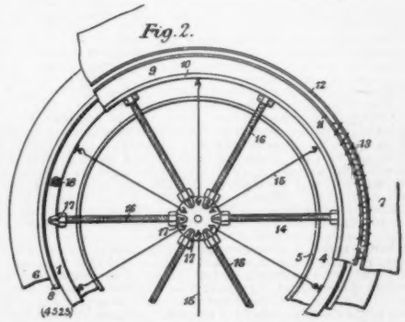


is pumped from the tank into the trough whenever the machine is working, and at the same time water which rises above a predetermined level in the trough is permitted to pass back to that tank. The usual moistening-roller *a* is, as usual, mounted in a trough *b*, while the yarn *c* to be wound passes from a bobbin *d* on to a cheese or the like *e*, passing over guide-rollers *f* and *g*. The guide-roller *f* is preferably mounted on the trough as shown, so that the amount of yarn which is in contact with the roller *a* can be regulated. The part marked *k* represents a tension device. In accordance with the present invention, below the trough *b* there is mounted a tank *j*. A pump *k* is connected by means of a pipe *l* with the tank *j*, and by means of a pipe *m* with a trough *b*. At the same time the tank *b* is provided with a further pipe *n*, which is connected to the same at a point level with the desired water-level in the trough *b*. This pipe *n* is so arranged as to allow water to pass from it into the tank *j*. The pump *k* is supposed to be connected up to any suitable going part of the winding-frame or machine, so as to be constantly rotated whenever the frame is working. *o* is a splash-board to prevent any water which may be thrown or squeezed out of the yarn from reaching the interior of the machine. This splash-board *o* is provided with a pipe *p* leading down to the tank *j*. The action of the device is as follows:—Whenever the winding-frame is running the pump *k* is operated, and in being operated raises water out of the tank *j* and feeds it into the usual trough *b*. As soon as the water in the trough rises above the predetermined level, determined by the mouth of the pipe *n*, it will overflow by the pipe *n*, and pass back to the trough *j*. By this means it will be seen than an absolutely constant water-level will be maintained in the trough *b* so long as there is any water in the tank *j*, with the result that the amount of water picked up by the roller *a* and imparted to the yarn *c* is absolutely constant, so that a uniform moistening effect on the yarn is ensured. (*Sealed.*)

MISCELLANEOUS.

4525/15. H. O. Short, London. Airships. [2 *Figs.*] March 23, 1915.—This invention relates to valves for gas-containers for airships and balloons, and which valves may be arranged to be positively operated by means of cords or the like, or may be automatic in action to allow the gas to escape when the pressure within the container exceeds a predetermined maximum. According to this invention, the frame of the valve is secured to one end of a flexible sleeve, the opposite end of which latter is secured to the surface of the fabric surrounding an aperture through the envelope of the gas-container, so that the valve-frame can be inserted and withdrawn through the aperture in the envelope from the exterior thereof, means being provided for retaining the frame in position when so inserted, which means are capable of removal to permit of the withdrawal of the valve-frame from said envelope. The valve consists of a frame, composed of two or more, preferably three, superposed rings 1, 2, 3 of wood or metal, between which rings the outer edge of an annular flexible diaphragm 4, which is to form the valve-seat, is clamped, the inner edge of the diaphragm 4 being provided with a non-extensible ring 5 of metal, wood, or the like Clamped between two of these superposed rings 2, 3 is one end of the sleeve or tube 6 of suitable fabric, or may be india-rubber or the like, the said sleeve 6 extending over the outer periphery of the rings 1, 2, while its opposite end is secured in any suitable manner, as by sewing to the interior surface of the fabric surrounding an aperture in the envelope 7 of the gas-container, the aperture being of such dimensions as to allow the valve and its frame to be placed within and be withdrawn from the envelope. This sleeve 6 forms the means for supporting the valve and its framework within the said envelope, and is retained in position within the said envelope by means of a short, rigid tube 8, which is removably placed between the inside of the sleeve 6 and the outer periphery of the rings composing the frame. The upper end of the rigid distancing-tube 8 bears against an annular diaphragm 9 of suitable fabric, the inner and outer edges of which are stiffened by means of non-extensible, may be metal, rings 10, 11, the outer ring 11 being of slightly smaller diameter than a non-extensible ring 12, which





edges the aperture in the envelope 7, whilst the inner ring 10 is of such a diameter as to leave a perfectly free gas-passage past the valve-seat. The annular diaphragm 9 is removably secured to the envelope by lacing 13, connecting the outer ring 11 of the diaphragm 9 to the ring 12 surrounding the aperture in the envelope 7. A movable valve 14, formed of a disc of suitable material, preferably metal, is supported by one of the superposed rings forming the valve-frame, the valve-disc being so formed, preferably concave, as to present an edge which bears upon the valve-seat. The centre of the valve is provided with means for connecting the inner ends of radiating wires or cords 15, the outer ends of which are connected to one of the superposed rings of the valve-frame at the opposite side of the diaphragm 4 forming the valve-seat, the said wires or cords 15 forming the means for controlling the movement of the valve 14 up to a predetermined limit. In order to ensure the valve returning to its seat, a plurality of radial springs 16 are provided, attached at opposite ends to the centre of the valve-disc and to the ring of the frame to which the distancing-wires 15 are attached. The radial springs 16 are preferably detachably connected to the valve or to the frame, or to both, and may be formed of india-rubber cord, having eyes 17 attached to the opposite ends to engage studs on the vave-disc and frame. The radial springs 16 are so arranged that they assume an outwardly inclined angle from the centre of the valve-disc to their point of connection to the ring, even when the valve-disc is in its normal position; thus, upon the valve being opened, the said springs are subjected to still further tension and they assume a still greater angle with respect to the said valve-disc 14. The superposed rings, between which the valve-seat diaphragm 4 and the end of the sleeve 6 are clamped, are connected together suitably, by means of bolts 18 which pass through the rings in the direction of their axes, and are secured in position by nuts, preferably wing-nuts, as shown, screwed on to the outer ends of the bolts 18, so as to be accessible from the exterior of the envelope 7 after removing the diaphragm 9, which is, as before stated, laced to the envelope surrounding the valve aperture. (*Sealed.*)